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OF THE

INSTITUTION OF NAVAL ARCHITECTS.

VOLUME XVII.

EDITED BY A. SEDGWICK WOOLLEY, A.I.N.A.,

SECRETARY TO THE INSTITUTION.

1876.

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OBJECTS OF THE INSTITUTION.

THE objects of the INSTITUTION OF NAVAL ARCHITECTS—which was established to promote the Improvement of Ships, and of all that specially appertains to them—are comprised under three heads:—

First, the bringing together of those results of experience which so many shipbuilders, marine engineers, naval officers, yachtsmen, and others acquire, independently of each other, in various parts of the country, and which, though almost valueless when unconnected, doubtless tend much to improve our navies when brought together in the printed Transactions of an Institution.

Secondly, the carrying out, by the collective agency of the Institution, of such experimental and other enquiries as may be deemed essential to the promotion of the science and art of shipbuilding, but are of too great magnitude for private persons to undertake individually.

Thirdly, the examination of new inventions, and the investigation of those professional questions which often arise, and were left undecided before the establishment of this Institution, because no public body to which professional reference could be made then existed.

BYE-LAWS AND REGULATIONS.

CONSTITUTION.

1. THE INSTITUTION OF NAVAL ARCHITECTS shall consist of four classes, *viz.*, Members, Associates, Honorary Members, and Honorary Associates.

2. *Members.*—The Class of Members shall consist exclusively of Naval Architects and Marine Engineers conversant with Naval Architecture.

3. *Associates.*—The Class of Associates shall consist of persons who are qualified, either by profession or occupation, or by scientific or other attainments, to discuss with Naval Architects the qualities of a ship, or the construction, manufacture, or arrangement of some part or parts of a ship or her equipment.

4. *Honorary Members.*—The Class of Honorary Members shall consist of persons who are eligible as Members, and upon whom the Council may see fit to confer an honorary distinction.

5. *Honorary Associates.*—The Class of Honorary Associates shall consist of persons who have contributed to the improvement of ships or their equipment, and upon whom the Council may see fit to confer an honorary distinction.

ELECTION AND DUTIES OF OFFICERS.

6. The Officers of the Institution shall consist of a President, Vice-Presidents, Members of Council, Associate Members of Council (not exceeding in number one-third the number of Members of Council), a Treasurer, two Auditors of Accounts, and a Secretary or Secretaries.

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7. A General Meeting of the Members and Associates of the Institution shall be held annually; and at this Annual General Meeting the Members of Council, Associate Members of Council, Treasurer, and Auditors for the ensuing year shall be elected.

8. At the Annual General Meeting Members only shall vote in the Election of Members of Council, and both Associates and Members in the Election of Associate Members of Council, the Treasurer and the Auditors.

9. As soon as may be convenient after the Annual General Meeting, the newly-elected Members and Associate Members of Council shall meet and elect the President and Vice-Presidents for the year, Members and Associate Members of Council both voting.

10. *President.*—Both Members and Associates of the Institution shall be eligible for election as President. The President shall preside over all Meetings of the Institution, and of Officers of the Institution, at which he is present, and shall regulate and keep order in the proceedings.

11. *Vice-Presidents.*—Both Members and Associates of the Institution shall be eligible for election as Vice-Presidents. In the absence of the President, one of the Vice-Presidents shall preside at the General Meetings of the Institution, and shall regulate and keep order in the proceedings.

12. In case of the absence of the President and of all the Vice-Presidents, the Meeting may elect any Member of Council or Associate Member of Council, and in case of their absence any Member present, to preside.

13. The Chairman at any Meeting of the Council or of the Institution, when the votes of the Meeting, including his own, are equally divided, shall be entitled to give a casting vote.

14. Persons holding the office of Vice-President shall at all times be entitled to sit and vote with the Council.

15. *Past Presidents and Vice-Presidents.*—All Members who have held the posts of President and Vice-President shall, while their connection with the Institution as Members lasts, be entitled to sit and vote with the Members of Council.

16. *Members of Council.*—Members only shall be eligible for Election as Members of Council at the Annual General Meeting.

17. *Associate Members of Council.*—Associates only shall be eligible for Election as Associate Members of Council at the Annual General Meeting.

18. The Direction and Management of the Institution shall be vested in the Council for the time being, the Associate Members voting with the Members of Council in all cases, except in the decision of questions directly affecting the forms of ships and the construction of their hulls.

19. The Council shall meet as often as the business of the Institution requires, and at every Meeting five Members of Council shall form a *quorum*.

20. The Council may appoint Committees to report to them upon special subjects.

21. All questions shall be decided in the Council by vote; but at the desire, expressed in writing, of any four Members or Associate Members present, the determination of any subject shall be postponed to the succeeding Meeting of the Council.

22. An annual statement of the funds of the Institution, and of the receipts and payments of the past year, shall be made under the direction of the Council, and after having been verified and signed by the Auditors, shall be laid before the Annual General Meeting.

23. The Council shall draw up an Annual Report on the state of the Institution, which shall be read at the Annual General Meeting.

24. It shall be the duty of the Council to adopt every possible means of advancing the Institution, to provide

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for properly conducting its business in all cases of emergency, such as the death or resignation of Officers, and to arrange for the publication of the Papers read at the Meetings, or of such documents as may be calculated to advance the objects of the Institution.

25. *Treasurer.*—Only Bankers, or Members of Council, or persons who have been Members of Council, and are still Members of the Institution, shall be eligible for election as Treasurer.

26. *Auditors.*—All Members and Associates of the Institution shall be eligible for election as Auditors.

27. The Auditors shall have access at all reasonable times to the Accounts of the pecuniary transactions of the Institution; and they shall examine and sign the annual statement of the Accounts before it is submitted by the Council to the Annual General Meeting.

28. *Secretary.*—The Secretary or Secretaries shall be elected by the Council, and shall be removable at the will of the Council, after due notice given. The salary of the Secretary or Secretaries shall be fixed by the Council.

29. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all Meetings of the Institution and of the Council; to take Minutes of the proceedings of such Meetings; to read the Minutes of the preceding Meeting; to announce donations made to the Institution; to superintend the publication of such Papers as the Council may direct; to have charge of the library, museum, and offices of the Institution; and to direct the collection of subscriptions and the preparation of accounts. He shall also engage, and be responsible for, all persons employed under him, and generally conduct the ordinary business of the Institution.

DESIGNATION OF MEMBERS AND ASSOCIATES.

30. Any Member, Associate, Honorary Member, or Honorary Associate, having occasion to designate himself as belonging to the Institution, shall state the class to which he belongs according to the following abbreviated forms, *viz.:* M.I.N.A.; Assoc. I.N.A.; Hon. Mem. I.N.A.; Hon. Assoc. I.N.A.

ELECTION OF MEMBERS AND ASSOCIATES.

31. *Admission of Members.*—Every Candidate for admission into the Class of Members, or for transfer into that Class from the Class of Associates, shall be more than twenty-five years of age, and shall comply with the following regulation:—

He shall submit to the Council a statement, showing that he has been professionally engaged in shipbuilding or marine engineering for at least seven years in some public or private shipbuilding establishment, or marine engine works, and setting forth the grounds upon which he bases his claims to be considered a professional Naval Architect, or Marine Engineer, and to be admitted as such to the Membership of the Institution. This shall be signed by at least three Members, whose signatures shall certify their personal knowledge of the Candidate, and approval of his statement; or, in the case of persons not British born, the signatures of three Members shall be required, in confirmation of their personal knowledge of the Candidate's scientific reputation.

32. These preliminary conditions being satisfied, the Council shall then consider whether the practical experience and professional attainments of the Candidate are such as entitle him to be brought forward by the Council as a Naval Architect, or Marine Engineer conversant with Naval Architecture. If four-fifths at least of the received votes of the professional Members of the Council are in favour of his application, and such four-fifths constitute a majority of the professional Members of the Council, his proposal for admission shall be

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submitted to the Members of the Institution (who shall have access to the applicant's statement) at an Ordinary Meeting of the Institution, for them to vote upon, by ballot.

33. *Admission of Associates.*—Candidates for Associateship shall submit to the Council a proposal for their admission, setting forth therein a statement of their claims to be admitted as Associates. Their proposal, if approved by the Council, shall be submitted by them at an Ordinary Meeting of the Institution, for the Members and Associates jointly to vote upon by ballot.

34. The proportion of votes for deciding the election of Members and Associates shall be at least four-fifths of the numbers recorded.

SUBSCRIPTIONS.

35. Each Member and Associate shall pay an Annual Subscription of two guineas in advance; the first Subscription being payable on his election, and all future ones on the 1st day of January of each year. Any Member or Associate withdrawing from the Institution after that date is still liable for the amount of Subscription due on that day.

36. Any Member or Associate may compound for his Annual Subscription, for life, by a single payment of not less than thirty guineas.

MEETINGS.

37. Meetings for the Reading of Papers shall be held as frequently, and at such times, as the Council may determine.

TRANSACTIONS.

38. The *Transactions* of the Institution, including the Papers read at the Ordinary Meetings, and Reports of the Discussions by which they are followed, shall be edited by the Secretary, and printed under the direction of the Council.

39. A copy of each Volume of *Transactions* shall be sent free to every Member and Associate.

40. The Secretary, under the direction of the Council, may dispose of the surplus stock of *Transactions* which have been published more than three years, at a price of not less than One Guinea a Volume, provided a sufficient number remain on hand to supply the probable demand of new Members and Associates to complete their sets by the purchase of the back Volumes.

CHANGE OF ADDRESS.

41. Members and Associates are particularly requested to communicate to the Secretary any change of address.

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INTRODUCTORY PROCEEDINGS.

THE Meetings of this, the Seventeenth Session of the Institution of Naval Architects, were held on the 6th, 7th, and 8th April, 1876, in the Hall of the Society of Arts, John Street, Adelphi.

The Opening Meeting was presided over by the Right Hon. Lord HAMPTON, G.C.B., D.C.L., President of the Institution, who commenced the proceedings by calling upon Mr. A. SEDGWICK WOOLLEY, the Secretary, to read the Report of the Council, which was as follows:—

REPORT OF THE COUNCIL, APRIL 6th, 1876.

"The Council are glad to report that the finances of the Institution continue in a sound and "satisfactory condition.

"The balance brought forward at the commencement of the current year (1876) was £487 19*s*. "Of this, £354 16*s*. 10*d*. has since been paid in discharge of liabilities then outstanding; and after the "payment of all the debts incurred last year, there remained a balance of £133 2*s*. 2*d*. towards future "expenditure, in addition to the ordinary income of the Institution. The estimate for the current year "is also satisfactory.

"In their Report last year, the Council recommended to the serious consideration of the Members "and Associates the Report of the Royal Commission on Unseaworthy Ships, and the 'Merchant "'Shipping Acts Amendment Bill,' which was then before Parliament. Want of time necessitated the "withdrawal of that Bill, but a short measure was introduced at the end of the Session to meet what "were considered to be urgent matters for legislation before the coming winter. This measure is only "to continue in force until the first day of October this year. A new Bill has now been brought before "Parliament to make permanent the provisions of last year. The Council considered this a matter of "such importance to the Members and Associates of the Institution that they appointed a Committee "to report upon the Bill.

"The Resolutions arrived at by this Committee have been forwarded to the President of the Board "of Trade for his information.

"The Council last year also drew attention to the fact that the Classes of the Royal Naval College "at Greenwich, of which the School of Naval Architecture and Marine Engineering forms a part, were "open not only to the Royal Navy and the Royal Dockyards, but also to private students; and they "expressed a hope that shipowners and builders, naval architects and marine engineers would not fail "to give the full benefit of the advantages which the College affords to those in whose professional "education they have interest or responsibility. They are sorry to find, however, that out of the nine "private students at present at Greenwich only one is an Englishman, the rest being foreigners.

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" In compliance with a request contained in a letter addressed to the President by the Lords of the " Committee of Council on Education, on behalf of the Loan Exhibition of Scientific Apparatus at South " Kensington, the Council have resolved to co-operate with their Lordships in the following matters, *viz.:* " 1*st.* In making a collection of models, apparatus, and drawings, illustrating the history of Naval " Architecture and Marine Engineering. 2*nd.* In holding a reception of distinguished foreigners " interested in Naval Science. 3*rd.* In attending Conferences at Kensington; and 4*th.* In placing a " series of *Transactions* on the table of the Exhibition.

" A letter has been received from the Franklin Institute at Philadelphia, U. S. A., offering the free " use of its Library and Reading Room to all Members of the Institution who may visit Philadelphia " during the Centennial Exhibition. Members and Associates wishing to avail themselves of this invitation " should apply to the Secretary for a letter of introduction.

" The Council have had much pleasure in granting leave to the Imperial Royal Naval Department " of the Austro-Hungarian Government to translate and reprint, for the use of their naval officers, some " of the Papers which have been read at our Meetings.

" The Council have to deplore the loss by death, of two of their number, Mr. Thomas Lloyd, C.B., " and Mr. Joseph Large; one Honorary Associate, Admiral Sir Baldwin Wake Walker, Bart. K.C.B.; " and seven Associates, Rear-Admiral F. A. Campbell, Captain J. G. Goodenough, R.N., Mr. William " Dudgeon, Mr. William Hawthorn, Mr. Evan Leigh, Vice-Admiral C. G. Robinson, and Mr. Charles " Vignoles, F.R.S."

The following List of Donations to the Library of the Institution was then read by the Secretary:—

" Proceedings of the Royal Society of London," Vol. XXIV. *Presented by the Royal Society.*

" Minutes of the Proceedings of the Institution of Civil Engineers," Vols. XXXIX., XL., XLI. and XLII. *Presented by the Institution of Civil Engineers.*

" Proceedings of the Institution of Mechanical Engineers," for 1875. *Presented by the Institution of Mechanical Engineers.*

" Journal of the Iron and Steel Institute," for 1875. *Presented by the Iron and Steel Institute.*

" Journal of the Royal United Service Institution," for 1875. *Presented by the Royal United Service Institution.*

" Transactions of the Royal Society of Victoria." Vol. XI. *Presented by the Royal Society of Victoria.*

" Transactions of the Institution of Engineers in Scotland," Vol. XVIII. *Presented by the Institution of Engineers in Scotland.*

" Annual Report of the Board of Regents of the Smithsonian Institution," for 1873-4. *Presented by the Board of Regents.*

" Lloyd's Register of British and Foreign Shipping," for 1875-6. *Presented by the Committee of Lloyd's Register.*

" Underwriters' List of Iron Vessels," for 1875-6. *Presented by the Underwriters' Registry of Iron Vessels, Liverpool.*

" The Engineer," for 1875. *Presented by the Proprietors.*

" Engineering," for 1875. *Presented by the Proprietors.*

" Iron," for 1875. *Presented by the Proprietors.*

" Revue Maritime," for 1875. *Presented by the French Ministry of Marine.*

" Annales du Génie Civil," for 1875. *Presented by M. Eugène Lacroix, Paris.*

" Rivista Marittima," for 1875. *Presented by the Italian Ministry of Marine.*

" Approximate Freeboard." By F. WYMER, Esq. *Presented by the Author.*

" Note sur les Indicateurs du Nombre de Tours par Minute installées sur la Corvette cuirassée ***La Thétis***." By Monsieur A. MADAMET, Ingénieur des Constructions Navales. *Presented by Admiral Paris.*

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"Mémoires de la Société Nationale des Sciences Naturelles de Cherbourg," Tome XIX. *Presented by the Société Nationale.*

"Nozioni Preliminari per un Trattato sulla Costruzione dei Porti nel Mediterraneo." By Signor ALESSANDRO CIALDI, Capitano di Vascello. *Presented by the Author.*

"De quelques Propriétés Mécaniques de differentes Vapeurs. Mémoire presenté le 4 Octobre, 1875, à "l'Acadèmie des Sciences." By Monsieur CHARLES ANTOINE. *Presented by the Author.*

"Note sur un Appareil destiné à Enregistrer à bord d'un Navire la Loi d'un Mouvement quelconque." By Monsieur A. MADAMET, Ingénieur des Constructions Navales. *Presented by Admiral Paris.*

The following Gentlemen (being duly recommended by the Council) were unanimously elected Members of the Institution:—

Lieutenant Constantine Artsayooloff, Naval Constructor, St. Petersburg Imperial Dockyard; Mr. Harry John Cornish, Surveyor to Lloyd's Register of Shipping; Mr. Edwin William De Rusett, Inspector of Vessels and Machinery to the Peninsular and Oriental Steam Navigation Company; Mr. Thomas James Dodd, Surveyor to Lloyd's Register of Shipping; Mr. James Fortescue Flannery, Engineer to Mr. E. J. Reed, C.B., F.R.S., M.P.; Lieutenant Ernst E. Goulaeff, F.R.S.N.A., Lieutenant of the Corps of Naval Architects, Russia; Mr. Charles H. Haswell, Engineer and Naval Constructor, New York; Mr. Percy Louis Isaac, Naval Architect, London; Mr. James Kirkwood, Chief Engineer in His Imperial Chinese Majesty's Navy; Mr. W. L. Mintonye, Naval Constructor in the United States Navy; Mr. Robert Assheton Napier, Engineer, Glasgow; Mr. William Parker, Chief Engineer Surveyor to Lloyd's Register of Shipping; Mr. William John Pratten, Chief Engineer at Earle's Shipbuilding Company, Hull; Mr. George James Rickard, Surveyor to Lloyd's Register of Shipping; Mr. Peter Morrison Swan, Naval Architect to Messrs. R. Napier and Sons, Glasgow; Mr. James Turpin, Manager to Messrs. Bowdler, Chaffer & Co., Seacombe, near Birkenhead; Mr. Luther Watts, Engineer and Naval Constructor, H.M. Dockyard, Portsmouth; Mr. Henry H. West, Chief Surveyor, Underwriters' Registry of Iron Vessels, Liverpool.

The Secretary next read the list of Officers of the Institution, and the following Gentlemen having been proposed by the Council were unanimously elected to be added thereto:—Peter Denny, Esq., Marine Engineer and Shipbuilder, Dumbarton; Edward James Harland, Esq., Marine Engineer and Shipbuilder, Belfast; and Henry Hyndman Laird, Esq., Marine Engineer and Shipbuilder, Birkenhead.

It was then proposed by Mr. E. J. Reed, C.B., F.R.S., M.P., and seconded by the Right Hon. Lord Hampton, G.C.B., D.C.L., and carried unanimously, "That H.I.H. the Grand Duke Constantine "of Russia should be invited to become an Honorary Associate of the Institution."

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INSTITUTION OF NAVAL ARCHITECTS.

Statement of Income and Expenditure for the Year 1875.

Dr.

1874.	£	s.	d.	£	s.	d.
Dec. 31st. To Balance:—						
In Treasurer's hands	332	13	1			
In Secretary's hands ...	19	17	5			
				352	10	6
1875.						
Dec. 31st. To Cash received:—						
Annual Subscriptions				798	17	4
Volumes sold				103	1	0
Rent from Canoe Club				20	0	0
Sundry Receipts				0	1	9
Admiralty Grant, 1875				250	0	0
				£1,524	10	7

Cr.

1875.	£	s.	d.	£	s.	d.
Dec. 31st. By Cash paid:—						
Rent of Rooms to 29th September, 1875	100	0	0			
Cleaning ditto to 23rd December, 1875	13	0	0			
				113	0	0
Attendance at Meetings, 1875	12	13	6			
Reporting at ditto	33	6	8			
Gas at ditto	3	0	0			
Abstract of Proceedings at ditto	43	14	0			
				92	14	2
Advertising, 1875	38	18	4			
Ditto, 1873	1	7	8			
				40	6	0
Printing Vol. XV., and Miscellaneous Printing, 1875 ...	213	3	0			
Reducing Drawings for Vol. XV.	12	0	6			
Binding Vol. XV.	32	7	2			
Copperplate Engraving, Vol. XV.	111	6	6			
Wood Engraving, Vol. XV. ...	6	6	6			
Lithography, Vol. XV.	3	10	0			
Distribution of Vol. XVI. ...	25	9	7			
				404	3	3
Wood Engraving, 1871	4	10	0			
Electrotypes, 1871	0	12	0			
Gas at Meetings, 1874	3	0	0			
				8	2	0
Preparing Diagrams for Meetings, 1875				6	13	0
Stationery, 1874				19	17	3
Fire Insurance to 25th March, 1876				1	0	0
Banker's Charges				0	3	2
Petty Disbursements and Postages				53	1	8
Expenses of Library				10	7	1
Salary of Secretary	250	0	0			
Ditto of Messenger	26	0	0			
Ditto of Occasional Clerk ...	11	4	0			
				287	4	0
By Balance:—						
In Treasurer's hands	437	18	6			
In Secretary's hands—						
Subscriptions Account ...	8	9	9			
Canoe Club Rent	20	0	0			
Current Account	21	10	9			
				487	19	0
				£1,524	10	7

A. SEDGWICK WOOLLEY, *Secretary*,
JOSEPH D'A. SAMUDA, *Treasurer*.

We have examined the above written entries with the books and vouchers, and find them correct.

ROBERT CARLYLE, } *Auditors*.
JAMES MACKENZIE, }

22*nd Feb.*, 1876.

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An Account of the State of the Funds of the Institution on 8th March, 1876, and of the Estimated Income and Expenditure for the Year 1876.

Dr.

	£	s.	d.	£	s.	d.
To Balance on 31st December, 1875 ...				487	19	0
,, Cash received:—						
Annual Subscriptions	261	3	10			
Volumes Sold	7	6	0			
Admiralty Grant, 1876	250	0	0			
Sundry Receipts	0	13	0			
Amount actually received				519	2	10
To Cash receivable:—						
Annual Subscriptions (say)	531	0	0			
Volumes Sold (say)	93	0	0			
Other Receipts (say)	20	0	0			
Estimated to be received				644	0	0
				£1,651	1	10

Cr.

	£	s.	d.	£	s.	d.
By Cash paid:—						
Rent of Rooms				25	0	0
Cleaning Rooms to 4th March, 1876				2	10	0
Printing Vol. XVI., and Miscellaneous Printing, 1875				230	1	0
Salary of Secretary (on account) ...	50	10	0			
Ditto of Messenger (on account) ...	5	0	0			
Extra Attendance (on account) ...	6	2	6			
				61	12	6
Engraving, Vol. XVI.				77	5	6
Reducing Drawings, Vol. XVI.				9	7	0
Binding Vol. XVI.				31	1	7
Stationery				7	7	3
Postages and Petty Disbursements				9	16	1
Bankers' Charges				0	3	6
Dispatch of Volume				1	2	6
Library Expenses				0	16	3
Amount actually paid ...				456	3	2
To Cash payable:—	£	s.	d.			
Rent and Cleaning, to 31st Dec., 1876 (say)	85	10	0			
Expenses of Annual Meeting (say) ...	93	0	0			
Advertising, 1876	39	0	0			
Salaries to 31st Dec., 1876	227	0	0			
Volume XVII. (every expense, say) ...	309	0	0			
Library Expenses	10	0	0			
Stationery (say)	8	0	0			
Furniture and Repairs (say)...	5	0	0			
Postages and Petty Disbursements (say)	45	0	0			
Insurance, 1876	1	0	0			
				822	10	0
Estimated Liabilities				1,278	13	2
Estimated Balance				372	8	8
				£1,651	1	10

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The PRESIDENT (Lord Hampton) then proceeded to deliver the following Opening Address:—

GENTLEMEN: I am very happy to have the pleasure of meeting you again assembled here for the important objects which we have in view, and I am glad to see so numerous and influential an attendance. It is not my intention on this occasion to deviate from the practice which has obtained from the commencement of this Institution, that your President should open the Annual Session by some few observations; but it is my intention to reduce those observations within the narrowest compass consistent with the objects which we have in view. The Papers that are coming before you I think I may say, without exaggeration, are not only of great but of unusually great interest and importance. They are Papers bearing directly upon those national questions which are now interesting the public mind to an unusual extent; and I think, with such Papers awaiting our attention, and with somewhat limited time to give to them, it would be presumption on my part, if—merely from the fact that I am one of many who take deep interest in these subjects—I were to detain you by entering into unnecessary details, knowing as I do the able Papers and the interesting Discussions which are immediately to follow. But, Gentlemen, as it is consistent with custom, and therefore I think my duty, to make some few observations, which may be appropriate to the commencement of a new Session, I cannot refrain from congratulating you on the gradual and constantly growing success and improved status of this Institution.

You have heard in the Report which has just been read to you that the main point which influences so greatly the prosperity of all Institutions, namely your financial condition, is of the most satisfactory character. We find another important fact in the growing desire on the part of gentlemen of various professions and in different parts of the country to become Members of this Institution, and to have the power of contributing to those useful subjects with which we have to deal. Another gratifying proof of the growing prosperity of this Institution to which I wish to call your particular attention, is found in the large number of very able Papers which have been sent in to be read to us during our Meetings. There was a time some very few years ago, when I was not without apprehension that from the somewhat diminished number of Papers which were presented to us, interest in the great subjects which we consider here was somewhat declining; but I am happy to say any such apprehension has been removed for the last year or two, and upon this occasion the number of Papers which have been sent in to be read at our various Meetings during the next three days is so large that I fear there may be some difficulty in having all of them read and discussed during the time at our disposal. All of you who are in the habit of attending these Meetings are aware that whenever there has been too great a number of Papers to be conveniently read, or when the length of the Discussions upon them has prevented their being read, it has been our practice from time to time to arrange that particular Papers should be taken as read and published in our *Transactions*. Well, Gentlemen, this is a resource to which under the pressure of want of time we have sometimes turned; but I think you will agree with me that it is not a satisfactory course, especially to those gentlemen whose Papers are not read; because it is very possible—indeed quite certain—that out of a number of Papers some will be on more interesting subjects than others, and some may be more ably written than others; but still I think there is no doubt whatever the writer of every Paper is sure to consider that his own Paper is written with the greatest ability and on the most interesting subject. Therefore it cannot be satisfactory to the writer to have his Paper practically laid aside, only to be read by those who subsequently study our *Transactions*.

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I fear, Gentlemen, it is only too probable that we must resort to some measure of that kind at our present Session, and this leads me to ask you—I will not now make any definite proposal, but I think that this is a fit moment under the circumstances to bring it before the Members of this Institution—to consider whether it may not be desirable to make some change in our usual mode of proceeding, with the view of accommodating a larger number of Papers. Many of you will doubtless recollect that on one occasion we extended our Session to four days instead of three. We met then, in the first instance, at Kensington, but we have never since repeated the plan of having a four days' sitting. I think if the number of Papers becomes so great as to make it inconvenient or impossible to consider them during three days, that it may not be an objectionable plan, and indeed may become desirable that we should extend our Meetings to four days. But there is another suggestion that I would venture to submit to you, and to ask you to consider—not as I say for any immediate decision, but as worth our consideration before another Session—and that is, whether it may not be desirable that our Meetings should not be strictly limited, as they have been heretofore, to one occasion in the year? It has been suggested, and I myself think it is worth our consideration, whether we might not have a second Meeting in the course of the year; and again whether it might not be desirable that any second Meeting we might determine upon should rather be held at one of our great shipbuilding outports than to be always held in London. It has been suggested, whether—having regard to the nature of the duties we have to perform and the subjects we have to consider—a Meeting at one of the large and important outports, where a great deal of shipbuilding is carried on, might not give facilities for the consideration of many of the subjects which come within the scope of this Institution? I only throw this suggestion out as I have said for future consideration.

Gentlemen, the Council have with a view to facilitating our proceedings on this occasion as far as they have been able, arranged the Papers which have been sent to us in classes, and precedence has naturally, and I hope you will think properly, been given to those Papers which relate to the great questions now being so fully discussed with regard to our ships of war. I will ask you to look at the programme of this morning, and I think you will see that it is difficult to overrate the importance of the Papers that you will now hear read. The first is by such a high authority as Mr. Barnaby, "On Ships of War;" the second is by Mr. Brassey, "On Unarmoured Ships;" the third is by Lieutenant Goulaeff, of the Imperial Russian Navy, on those singular vessels of which we have lately heard so much—the circular iron-clads; and the fourth is, "On Cellular Ships of War." There is another, which I have no doubt will be a very important and interesting Paper, by Mr. Reed, "On certain Austrian "Iron-clads." Gentlemen, these Papers relate to questions which are now being so largely discussed, and which are exciting very much interest both in and out of Parliament. I have already said that it would be presumption on my part and a waste of your valuable time, if I were to enter into anything like detail, or into any extensive statement of such views as I may have been led to form upon these questions. You will all be desirous to proceed to a consideration of these Papers, and I will only say that I do most earnestly hope that our Discussions may tend to throw much light upon the great questions involved in them, namely, the best construction of our ships of war, and the comparative strength of armour and of guns. The Paper of my honourable friend, Mr. Brassey, is one which I am sure we shall hear with interest. It is on a subject upon which I confess I have myself for some time felt strongly, namely, the extent to which the policy of this country requires that we should have a large fleet of unarmoured but heavily-armed vessels for the protection of our own commerce and attack upon that of our opponents.

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And, Gentlemen, there is another question which is comparatively new, and upon which I hope we shall hear an interesting Paper read to-day: I mean the new sort of attack against which the ships of England will have to defend themselves. Hitherto we have only thought of the attacks above the water—we have only thought of the question between the gun that is to attack the ship and the armour that is to protect it; and I am disposed to think that I shall only say that which all experience has proved when I state to you my own belief, that do what you please with regard to strengthening armour, you will find that the gun is the stronger. But now we have to consider not only how we are to be protected above the water, but how our ships are to be protected below the water from the attacks with which they will doubtless have to contend from rams and torpedoes. Hitherto, I am sorry to say, the effect of the ram has been chiefly exercised upon our own ships. I hope that will not continue to be the case, but that we shall consider well how to make it available against our enemies, and above all how to protect ourselves. It is with this view, I think, that great interest will attach to the Paper which we are to hear this morning from Mr. Boolds, "On Cellular Ships of War." That is somewhat a new phrase, but I suppose Mr. Boolds will tell us it is only an extension of that mode of shipbuilding which has been in practice for merchant ships as well as men-of-war for a long period of time, which is the system of water-tight compartments. On this question, no doubt, Mr. Boolds will give us very interesting views. Well, Gentlemen, these are the questions with regard to our men-of-war which we shall have to consider. Not less interesting, I think, are the questions which are now being so widely discussed with relation to our mercantile marine. There is, as you know, a Merchant Shipping Bill at this time receiving the consideration of Parliament, and I am glad that amongst our Members here I see at this moment no less than three or four distinguished Members of the House of Commons, who are as competent as any men in this country can be to give good practical advice to Parliament on these questions; and I certainly am one who looks with extreme anxiety to the great importance of this Merchant Shipping Bill being passed in the most acceptable and useful form; when I say "acceptable," I mean that I desire to see it passed in a shape which shall not give just offence to, or excite reasonable alarm on the part of the shipowner, while it shall protect those who navigate the sea from those dangers to which they have been too much exposed.

Gentlemen, last year it was my duty to call your attention in my opening observations to the Report which we had then recently received from the Royal Commission which sat upon this subject. Now we are to reap the fruits of that report from the Royal Commission, and I hope that both in Parliament and among the public there will be no shrinking from what I believe to be the real condition of our mercantile marine at the present time. Perhaps the public in general are hardly aware of the striking fact that our mercantile marine at this moment consists of not less than 12,000 ships over 100 tons—that of ships of 100 tons and upwards we have no less than 12,000. I have reason to believe, from all the information I have received on this subject, that it would be not an unfair division of that great number of 12,000 merchant vessels above 100 tons to say that they may be divided into two not very unequal halves, one of which are classed ships, and are I believe as fine if not finer than any merchant ships in the world; while the other, and I believe somewhat the smaller half, but still a number not very much less than half, are unclassed ships, and I am afraid that no inconsiderable proportion of them are not worthy of the reputation of this country as a mercantile nation. Gentlemen, here of course is the ground upon which we are looking anxiously for the decision of Parliament, and I think I shall only speak the feelings of many of those who hear me when I express my hope that some mode will be adopted of classing the

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greater portion of these ships, and taking proper care that they shall be worthy of being classed among the merchant ships of England.

Gentlemen, Papers bearing upon these interesting matters relating to the merchant service will be found among our list, and one—perhaps the most important—is a Paper on a question the importance of which all the professional men who now hear me well know, but of which I believe the public at large have very little idea indeed; and that is the importance of having our iron marine built of proper metal. I am afraid that no inconsiderable portion of the casualties that have befallen our merchant service have arisen from the fact that all our iron ships are not built of quite such good iron as they ought to be; but I am very glad to find that one of the Papers to be submitted to you this evening is a Paper on the quality of the iron which is used for the building of our ships, and to-morrow there will be another Paper on the quality of the steel. These, Gentlemen, are questions of practical importance, and I think that whatever information may be contributed by competent persons will be extremely valuable, and will help to improve the state of our merchant service.

Gentlemen, there are numerous other subjects—Papers on pumping and on ventilation—hydraulic propellers, and various other most interesting matters with regard to the merchant service, but I will not detain you by further reference to them. The subjects on which I have now touched are the subjects which you will have to consider and discuss during the next three days; and I venture to say, without exaggeration, that I know of no Institution and of no body of men by which such subjects can be discussed with such good hope of practical results, as by the Meeting which I have now the honour of addressing. We see here distinguished naval officers; we see here eminent naval architects; we see eminent engineers; we see merchants, and we see great shipowners; and we see these gentlemen assembled here together to listen to Papers by competent writers, and to listen to Discussions by competent speakers. I cannot myself believe that such Papers can be discussed, and such Discussions be carried on and considered by a body of gentlemen so highly competent without contributing greatly to the welfare and the best interests of this country; and I will conclude these few introductory observations, in which I trust I have adhered to my intention to be brief, by only expressing my earnest hope that for many years to come this Institution may grow in success and in importance, and continue to promote those great and desirable ends for which it was first established.

[The Report was then adopted.]

Since the issue of Vol. XVI. the following Gentlemen have been added to the List of Members and Associates respectively:—Lieut. Constantine Artsayooloff, Messrs. Harry John Cornish, Thomas James Dodd, James Fortescue Flannery, Lieut. Ernst E. Goulaeff, Messrs. Charles H. Haswell, Percy Louis Isaac, James Kirkwood, W. L. Mintonye, William Parker, William John Pratten, George James Rickard, Edwin William De Rusett, Peter Morrison Swan, James Turpin, Robert Assheton Napier, Luther Watts, and Henry H. West, Members; and Messrs. Charles Murray Aynsley, C.B., Captain R.N.; Crescencio Brum, Imperial Navy Yard of Rio Janeiro; John Frederick Crease, Major

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Royal Marine Artillery; Captain Charles Chapman, author of works connected with naval matters; Messrs. Richard Churchill; Edward Crofton, Barrister-at-Law; T. E. Edwards, Lord Elphinstone, Chevalier Charles De Hoffman, Messrs. Sachin Sasoa, Earle's Shipbuilding and Engineering Company, Hull; and James Carmichael Spence, India General Steam Navigation Company, Associates.

During the same period the Institution has sustained the loss of the following Associates by death:— Sir Baldwin Wake Walker, Bart., K.C.B., Honorary Associate; Josiah Barrett, Esq., William Hawthorn, Esq., Evan Leigh, Esq., Vice-Admiral C. G. Robinson, Joseph P. Ronayne, Esq., M.P., James Urquhart, Esq., R.N., Charles Vignoles, Esq., F.R.S., and Admiral R. L. Warren, Associates.

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PAPERS AND DISCUSSIONS.

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ON SHIPS OF WAR.*

By N. Barnaby, Esq., C.B., Director of Naval Construction of the Royal Navy, Vice-President.

[Read at the Seventeenth Session of the Institution of Naval Architects, 6th April, 1876; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

I propose to offer a few general considerations as to ships of war, with a view to clearing the ground for our debates, and endeavouring to define our present position.

It is a frequent remark of journalists that the administrators of the Navy have no plan, and that ships are added to the Navy, at great cost, which, in the course of a few years, will become obsolete. If it could be established that, when the programme of shipbuilding operations for the year is prepared, due heed is not given to the forces of other powers—that would indicate a want of plan culpable enough; but I take it that this is not what is meant. There is a vague idea that the administration should have such foresight as to avoid taking a single step out of the straight road into the position we shall occupy ten or twenty years hence. But this expectation on the part of the public does not take due account of the great change in conditions introduced by new inventions. Take, for example, the invention of the screw-propeller; and of incendiary and explosive shells.

The introduction of the screw-propeller into the Navy in 1844 made a magnificent Navy obsolete; the realisation of the terrible effects of shell fire in 1854 again rendered our grand screw line-of-battle ships and frigates things of the past. I grant that we are bound to take care not to go on so obstinately and so fast in any road as to neglect the signs and warnings that are given us. It is my duty, for example, to detect at once the appearance of a new peril for the ships, or a new source of power for them. I should not be fit for my post if I allowed the history of the past, or the contentions and cares of the present, to draw my eyes away from the threatenings and the promises of the future. Our national position demands that we should immediately appropriate new forces, and our public spirit and wealth always make it possible to do so. I take high ground for the naval constructor, because it is only upon such ground that he can command the acceptance

* Received 30th March, 1876.

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of such statements as I desire to make. I am going to ask you to believe, without giving you the proofs, although I am prepared to give them whenever and wherever you will, that the circumstances and conditions of naval warfare stand at present as follows:— (1) Looking at the relative distances within which the gun, the torpedo, and the ram are operative, and the risks of failure in striking with them, the gun occupies the first place, and the ram the last, as instruments of naval warfare. (2) From this it follows that ships built only for ramming forego the use of two more important weapons. That a ship built wholly for torpedo service is better than a ram, but is still inferior to one built for service with guns only. The advantages of combinations of these weapons follow the same rule. (3) That while the gun is, on the whole, the superior weapon, it can be resisted more easily than either of the others. If it were as difficult to resist the blow of the gun as it is the blow of the torpedo or the ram, naval warfare would cease to be practicable. (4) The growth of resistance to the gun encourages further increase in the power of the gun, and there appears at first sight to be no limit to this increase. The limit will probably be found in the cost of putting the gun afloat with proper protection for it, and proper speed. The cost will be reckoned in view of the exposure of each such gun to loss by the power of the ram and the torpedo when they can be brought within the proper range of their operations. Some people appear to suppose that the constructors of the Navy are only just becoming alive to the dangerous nature of the torpedo, and its probable effect upon the ships. I may, therefore, perhaps be allowed to refer to an opinion expressed in this matter in January, 1867, at the Institution of Civil Engineers, by an Admiralty Constructor, *vide* Vol. 26 of *Transactions* of that Institution. He said,—"It must be "borne in mind that, however thick the armour, the bottom of the ship was left as weak "and defenceless as ever. Torpedo boats made proof against almost any firing that "could be directed against them, could be carried in seagoing ships, and doubtless would "be so carried and employed. In view of these new and undeveloped, but terrible "agencies, it was desirable not to create a large fleet like that recommended, at the cost "of many millions of money, which, although secure from gunpowder above water, "might easily be rendered obsolete and useless, because undefended from gunpowder "fired from beneath." The author of these remarks was myself. (5) The torpedo can be made, within the proper range of its operations, irresistible.

Before proceeding further upon this matter, I think it desirable to refer to what has already been done in ships of war for the purpose of resisting rams and torpedoes. There have been four important cases of ramming between English iron-clads, *viz.*, the *Hercules* ramming the *Northumberland;* the *Minotaur* bow on to the *Bellerophon;* the *Resistance* bow on to the *Devastation*, and the *Iron Duke* bow on to the *Vanguard.* In all cases the blow was unexpected, and the ship was unprepared. In three out of the four

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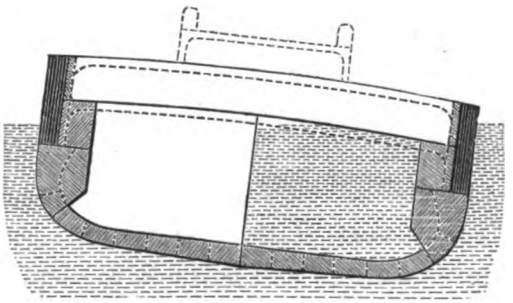
cases the provisions made against an accidental blow of the ram was effective. In the first the outer bottom was torn open, and the wing compartment filled, but no further harm was done. In the second, the armour and frames were driven in bodily four or five inches, but the leakage was confined to the wing compartment. In the third, the armour was not much displaced, and there was no leakage. In the last, the ship was struck with a force as great as is ever likely to be attainable in an action, and in the most fatal place. She was unprepared to receive it, but she, nevertheless, floated more than an hour, and only took in water at the rate of from 15 tons per minute at the commencement, to 27 tons per minute just before she sank. From this we may conclude that the gross area of the openings in the inner bottom could not have exceeded a square foot. If these results are compared with the results of collisions in ordinary ships it will be admitted, I think, that much has been done in ships of war in the way of protection against the ram. Moreover, the Vanguard was greatly inferior in the matter of bulkhead divisions to the ships now in course of construction, such as the *Dreadnought*, the *Alexandra*, the *Temeraire*, the *Nelson*, *Northampton*, and the *Inflexible*, as any one may see who will take the trouble to inspect those ships.

In the matter of defence against torpedoes, the experiments against the bottom of the *Oberon* showed a far higher resisting power than the double bottom system had been credited with; and, as to one of our most recent ships, the *Inflexible*, I give a sketch showing what would happen under the action of Whitehead torpedoes. Notwithstanding this, I say it is idle to attempt to form the bottom of a ship strong enough to resist a fair blow from a powerful torpedo. The utmost that can be done is to keep the disabled ship afloat after she has received such a blow. It would be possible to protect the bottoms of ships with armour to withstand the present charges of the Whitehead and Harvey torpedoes, but this must be done either by giving up some of the defence against the ram in speed, or of the defence against the gun in armour, or by building larger and more costly ships. When this was done, it would only be necessary to increase the charges of the torpedoes, and the armour we had applied would become vulnerable. (6) If the blows of the torpedo are to remain irresistible when fairly delivered, it remains to be considered in what manner and to what extent the attack can be met, because it would appear that it only needs high speed and armour defence in the torpedo ship to give her control over the situation and enable her to come down upon her adversary in the open day and deliver her fatal blows; and, under the cover of darkness, she would not even need armour. The attack, moreover of several fast unarmoured rams or torpedo ships



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upon a somewhat slower armoured ship, although involving the probable destruction of some of the attacking vessels, would still expose the armoured ship to fatal blows. (7) The possibility of such attacks by armoured rams or torpedo ships, or by numerous unarmoured vessels of this kind, exposes the costly armour-clad ships to a risk which they ought never to encounter alone. The assailants ought to be brought to bay before they could get within striking distance of the iron-clad by consorts armed like the attacking vessels with the ram and the torpedo, which may take, like them, the chances of being sunk. In other words, I contend that the defence against the ram and the torpedo must be sought for not in the construction of the ship alone or mainly, but also and chiefly in the proper grouping of the forces at the points of attack. Each costly iron-clad ought to be a division defended against the torpedo and the ram by smaller numerous but less important parts of the general forces. (8) If the foregoing considerations are correct there is still place in naval warfare for costly iron-clads with thick armour and powerful guns. There is place also for association with them of unarmoured vessels armed with the torpedo and manned by brave men. (9) There is work also for lightly-armoured and partially-armoured ships, because any armour obliges the adversary to increase the power and diminish the number of his guns. A thinly-armoured ship will receive fewer effective hits than an unarmoured ship, and of the hits which are effective only a small proportion will have any chance of bursting within the ship, because thin armour explodes most shells in the act of perforation, whereas with no armour the explosion would take place after perforation. It may be said that with no armour there might be no explosion, but the chances are small of an explosive projectile getting into a ship, across the decks, and out at the other side without meeting with enough resistance to explode it. (10) Under the name of armoured ships I include all ships in which the means of propulsion and of offence are protected against artillery by iron plating, whether that plating be vertical or horizontal. Horizontal armour is displacing or supplementing, and is likely to displace or to supplement still more in the future, vertical armour. The change which has already taken place in this respect may be best indicated by comparing the following ships;—

Displacement.		Weight of Vertical Armour and Backing.	Weight of Horizontal Armour.	Total Weight of Armour.
		Tons.	Tons.	Tons.
10,627	*Minotaur*	2,100	*nil.*	2,100
8,677	*Hercules* ...	1,849	100	1,949
11,165	*Inflexible*	2,585	967	3,552
8,492	*Ajax* ... ... / *Agamemnon*...	2,000	720	2,720

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Vertical armour must always be retained to protect the openings in the horizontal armour, the buoyancy and stability of the ship, and, to some extent, the guns and gunners. (11) The introduction of armour-plating has tended to the advantage of England, as compared with her rivals, because it has admitted of the use of iron instead of wood in the construction of ships of war, and it is now established that it not only admits of the use of iron, but it absolutely excludes the use of wood, except for secondary purposes. The establishment of this fact has greatly depreciated the value of Continental iron-clads. Our dependence upon foreign markets for supplies of materials has therefore been got rid of, and our rivals are obliged to come to us for their materials, and follow us in the modes of construction. (12) The torpedo has served, and will serve England also, by giving us the means of defending our coasts and harbours effectively, and the invention of the Whitehead and Harvey torpedoes in particular has placed in the control of our grand fleets of unarmoured merchant ships a weapon with which the most powerful ships of war may be disabled. It therefore raises the value of unarmoured ships for fighting purposes; and this makes our possession of numerous unarmoured and inexpensive peace vessels, and of vastly more numerous and swift merchant steamers, a source of great strength in war. (13) The effect of these conditions upon the matter of speed—which is always a vexed question—is to reduce the speed necessary in the iron-clad for line-of-battle, to maintain it at about the present standard for armoured cruisers, and to increase it in special vessels for despatch service.

I know that these positions are not unassailable, but I believe them to be impregnable. Whoever accepts them will find in them a security against any alarm about our position as compared with Foreign Powers, but he will not find any excuse for ceasing to build iron-clad ships. In my view the iron-clad must continue to occupy the first place in naval warfare; and we have only to remember in how many different and distant parts of the globe we should require to be present in force in a time of war with any great maritime Power to see how far short the number of our iron-clads falls of that which our extended and proud dominion requires.

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DISCUSSION.

Admiral Sir R. Spencer Robinson, K.C.B., F.R.S.: Lord Hampton and Gentlemen,—I knew, before I came to this Hall, we should hear a most instructive Discussion; and that we should, at any rate, hear Papers of the greatest possible importance, put forward by gentlemen of undoubted ability; and that the interest we should all feel in hearing these Papers read and in the Discussion that might possibly follow could not well be exaggerated. I must say the Paper that Mr. Barnaby has just concluded has not only come up to my expectations, but has gone considerably beyond them. I take the liberty of speaking very early in this Discussion, for reasons that I shall come to presently; but one of the very first reasons I have for addressing myself to you is the extreme importance of the subject matter in hand, and the great importance that we should know and understand, on proper and scientific principles, on what ground it is we propose to have an iron-clad navy; and it is in corroboration of the remarks that Mr. Barnaby has made on this subject that I venture to speak to you at all. If I did not know, as well as many gentlemen in this room know, that extreme uncertainty, doubt and hesitation prevail, where no doubt no uncertainty and no hesitation ought to prevail—if I did not know that at this moment those who are charged with the important duty of providing this country with a sufficient and an adequate naval force, are so entirely at sea as to what is the right style of ship to construct, that they are meditating appealing from their professional advisers to a Royal Commission, well or ill constituted—I should not, perhaps, have begun so early in this debate to address you; but I feel the importance of our thoroughly understanding what are the requirements of a ship of war of the present day, and in what measure the plan and system that Mr. Barnaby has developed are likely to meet our requirements, and what we do want so far as the naval architect can provide them. Mr. Barnaby has, with great judgment, shown you one of the things which, we all well know, is in very great danger of being decided in a manner adverse to the requirements of this country; he has shown you, that, with all the inventions, and with all the ability that the best naval architects can bring to bear upon this question, we cannot dispense with armour plating. It is a very great progress that has been made in that way. I have seen it repeatedly urged, in newspapers and in other places, that the time has come to throw off our armour plating, and to engage ourselves against armour-plated vessels naked and helpless. If that opinion was not more prevalent than it is, there might be less occasion for proving, as Mr. Barnaby has proved—and I think everybody who has listened to him must have been convinced by what he has said—that we cannot, at this moment, or for a long time to come, dispense with vertical or horizontal armour plating. Our President, in his observations, alluded to the great difficulties that ships of war would have to contend with through the action of torpedoes and torpedo vessels; and the observations which he made are no doubt perfectly true. This difficulty is not, as Mr. Barnaby said, one recently known to naval architects; those able gentlemen, with whom I co-operated, and with whom I underwent many years of laborious work at the Admiralty, were perfectly aware of the risk to our armour-plated ships that the invention of the Whitehead torpedo occasioned. Mr. Barnaby has quoted something that he said in the year 1867. I was myself examined before Lord Dufferin's Committee—that was in May, 1871—and I said, that if I were First Lord of the Admiralty, or Controller of the Navy, or had the smallest influence with anybody who had the power in their hands, I should devote myself day and night, and before all other subjects, to the proper construction of a torpedo boat; and that the first naval power that had that torpedo boat would be master of the seas. Now, Gentlemen, five years have elapsed since that evidence was given, and seven or eight years have

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elapsed since Mr. Barnaby gave his evidence, and at this moment we are without a torpedo boat; not that there are not designs, not that there are not plans in that office at Whitehall—because there they are—but it is because those who are charged with the important duty of taking care of Her Majesty's Navy cannot make up their minds what sort of torpedo boat they shall build. If an Institution like this would directly and positively show that delay in making up your minds as to the instrument of war you are to use is highly culpable—if they were to express the opinion I boldly announce here, that it is not right in the persons who have charge of the naval administration of this country to defer and to put off making a decision on subjects of such importance as this, our meeting this day and at other times may probably be more useful than it is. We have met here often; these subjects have often been discussed; time after time we hear of the very thing that is wanted for the due strengthening of the British Navy; the plans are there; the naval architects do their part; the able seaman who presides over the construction of the Navy is there, and has pointed out, again and again, what should be done and ought to be done; and look at our position: we are still as we were before; we are without a torpedo boat, and we are without—in the estimation of the public, at any rate—any definite plan for the construction of our future ships of war. Mr. Barnaby has most ably pointed out to you that a well-devised and well-planted torpedo will, probably, destroy even the *Inflexible;* but he has also pointed out to you the proper way to meet that: not by adding iron to iron, and sacrificing all the good qualities of the ship to armour plating put under the bottom, but by having each of the large ships of war accompanied by its attending pilot fish—if I might say so—who shall take charge of the ship, with their explosives and their rams, and enable the ship, by its powerful artillery, to sweep the seas and destroy all that comes before it. No suggestion more valuable for the purposes of war has been made by any person within my knowledge than the able suggestion which has been made by Mr. Barnaby, that the true mode of defending our heavy iron-clads from these attacks is by the counter attack of torpedoes and rams. No fleet, therefore, can be considered a fleet, and in my humble opinion no ship like the *Inflexible* can be considered a ship of war till she has her attendant rams and torpedoes to meet those attacks to which she is sure to be subjected. I do hope that the Institution will believe that on these points I am not in any way influenced by hostile feelings towards any man, or towards any set of men. I am simply one of those outsiders who see with very great regret, who see with very grave apprehension, that while this country has, without exception, at its command the ablest talents for designing, and the most powerful intellects for building ships and engines—while it has at its command, as we have seen to-day, suggestions of the utmost value, and of the utmost importance, freely made by its public servants, we are standing still and not making the progress that we ought to make. That is a bold assertion, but one or two figures will show it. There is no want of designing power at the Admiralty; there is no want of designs in the Admiralty's hands, and there is no want of money; for the country has voted it freely. But what do we want? We find that ships are building for seven years, we find that ships are building for eight years, and the ingenuity and invention of men, especially as far as engineers of distinction are concerned, make rapid progress, that by the time our ship has been eight years on the stocks, something better than that ought to have been on the seas. These are not subjects for which we can blame our naval architects. They provide the plans, they show the utmost ingenuity, they labour with astuteness and talent to give us what we ought to have, and instead of that being accomplished within a reasonable time we find our ships seven and eight years building. Allow me to call your attention to one case. I know I shall offend some people by what I am about to say, but I trust they will forgive me. In the year 1869 I was

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instrumental, under the guidance of a much abler man than myself, in getting the *Devastation* and the *Thunderer* built. Many people do not approve of those ships, and of course are at perfect liberty to have their own opinion, and can give good reasons no doubt in justification of not approving of them, but I simply want to point out that they were approved by the superior authority, the Admiralty, very highly. In 1876 the *Devastation* is the only one of those ships which we laid down in 1869 that is finished. The *Thunderer* is not at this moment finished. As I said before, let no one suppose that naval architects are in the least to blame for that. When I say that, I say as boldly as I can that the Admiralty is to blame for it, and the Naval Administration of this country is to blame; and if we are to have an efficient Navy we must learn that when we lay down a good plan of a ship, that ship should be completed within a reasonable time. We know whose fault it is that that is not done. It is perfectly ludicrous. If you turn to the Naval Estimates of this year you will find that some of the ships that were laid down five years ago will not be finished till 1878. I might go to much greater length and detail into the subject of non-finishing ships, but perhaps it is rather more fit for discussion in the House of Commons than it is at the Institution of Naval Architects. Still, my chief object in saying what I have said is that because publicly and privately I hear everywhere said, "Oh! there is no plan,"—Mr. Barnaby adverted to it—"naval architects do not know what to do; we are at sea entirely, we had better leave off building "ships." It is so very easy to say when a difficulty is presented to you: "Let us wait." That reminds me of an old Turkish word which I used to hear when I was in the *Levant*, which I think might very well be applied to these matters. "Let us wait." There is a great deal of prudence sometimes in waiting, and not making up your mind till you know what is right—that is quite proper. But what happens if other people do not hold their hands? What happens if other people do not say "Let us wait," but say "Let us go ahead?" The result is the maritime power and supremacy of this country passes away into other hands. I do not find that the German Navy, or the Russian Navy, or the navies of other countries hesitate as to the points upon which we are shivering and shaking, and trying to find a solution, and asking for a Royal Commission one year, and a Committee of distinguished scientific people another year, but I find them going ahead, and I find in every quarter of the globe wherever the British flag flies powerful iron-clads about which the constructors have no doubt that they will quite answer the purposes for which they are designed, without being in every respect perfect ships of war. Our policy is clear before us. The greatest objection that I ever heard, the most reasonable and the most sensible objection to large iron-clads and the thickness of armour, is their liability to be destroyed by ram or torpedo. I am perfectly satisfied, and I think Mr. Barnaby and everybody must be satisfied, that by a proper system of bulkheads, by going as far as possible in the direction of the cellular ships, which will be talked of and described hereafter, the blow of the ram may not prove as fatal as the late unfortunate accident to the *Vanguard* has led people to suppose it would be. I am quite satisfied also that Mr. Barnaby has hit upon the right plan of defending such ships from the attacks of torpedoes. It is by counter attack that you must succeed, and not by piling mountains of iron upon the sides, &c., of your ships. I am perfectly aware that I have already taken up the time of the Meeting too long, but there are one or two other observations which, perhaps, I may be allowed to make, and when another Paper is read I shall probably ask you to listen to me for a few moments. In the meantime, Gentlemen, I thank you very much for your attention.

The PRESIDENT: Gentlemen, before any one else rises to speak on this very interesting Paper will you allow me to supply an omission? I do not rise to address myself to Mr. Barnaby's Paper, but merely

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to supply an omission of which I was guilty at the commencement of our proceedings, which was to remind the Meeting of the old rule, which I hope will be strictly adhered to, that no Paper shall occupy more than twenty minutes in being read, and further that no speaker in the Discussions shall occupy more than ten minutes. I hope that the Meeting will support me in enforcing this rule, because it is dictated by a sense of fairness to every one, and that we may all have a chance of expressing our opinions.

E. J. REED, Esq., C.B., F.R.S., M.P. (Vice-President): My Lord and Gentlemen, I do not rise to take any extended part in this debate, but for the purpose of endeavouring, if possible, to give a particular direction to one part of it. Mr. Barnaby's Paper sets forth a novel and very important question, which has already received the concurrence of Sir Spencer Robinson. Under item 7 he states that the proper way to defend armoured ships from rams and torpedoes is by auxiliary vessels, and I must say that this idea seems to me to be likely to prove important from what I have found to be generally a very good reason, that is, that there is a sort of concurrence of opinion setting in that direction. I have had several letters lately from eminent men, some of them naval officers, and some of them not, suggesting this very point.* Now there being a great many of the ablest and most influential of the naval officers of our country present what I should like to learn from them, if it should please them to take part in the debate, is, how far the necessity, if we admit it to be a necessity, of employing auxiliary vessels for the defence of iron-clads, will tend to limit or do away with the use of iron-clads themselves at sea? What I want to know is how far naval officers will consider it practicable to keep these auxiliary vessels in company with iron-clad vessels on general sea service. That is a very important question. It is one that I am entirely unable to form any opinion upon, and one upon which I should like to hear the opinions of naval officers very much

* The following is a copy of a letter addressed to Mr. Reed by Sir Samuel Baker upon this subject :—

"Sandford Orleigh, Newton Abbott,
"March 1st, 1876.

"MY DEAR Mr. REED,—Your letters in the *Times* always afford me a deep interest, as all that pertains to ships of war "has long been a hobby of mine. You will, therefore, I hope excuse me for inflicting upon you an idea upon which I "should much value your opinion.

"Accepting as a matter of course that the comparatively short handy iron-clad must be the fighting giant of the present "and future, instead of the long ships of the *Minotaur* class—it appears to me that EVERY iron-clad should possess two "tenders that would *absolutely be inseparable attendants.*

"These tenders should be wooden vessels with an *immense* speed—fitted as rams—tonnage about 2,500—a box battery "amidships perfectly shot-proof, to protect an armament of two 35-ton guns, and two smaller guns (not iron-clad piercers).

"Each accepted iron-clad of the Navy would thus be accompanied by two fast handy rams, which would never leave "her, but would belong to her as entirely as the horses do to the field gun.

"These rams would in action wait upon the iron-clads, and engage the enemy by signal by ramming, or avoid him "according to orders. Each ram tender would be provided with two torpedo steam launches—thus in smooth weather a "single iron-clad (carrying himself two torpedo launches) would exhibit force as follows:—

"1 Iron-clad,
"2 Rams,
"6 Torpedo Launches.

"It strikes me that no one, either professional or otherwise, can foretel the requirements of a naval engagement of the "present day; therefore it is necessary that a *composite* force, something like that now proposed, should invariably be "united.

"Upon this principle two iron-clads would form a squadron, as they would comprise a force of six powerful vessels "with twelve torpedo launches.

"Such a force would be fitted for any work—in any portion of the globe—and the wooden vessels could carry a large "amount of coals to assist the iron-clad if necessary.

"Very truly yours, "(*Signed*) SAMUEL W. BAKER."

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indeed. It seems to me that you cannot keep the auxiliary vessels in company with the iron-clad which is to be defended by these extraneous means at sea, and they are pretty nearly always at sea; and under the conditions which are likely to arise there, this proposal practically comes to an abandonment of the use of armour-plated ships at sea, because if they require the defence of consorts and auxiliaries, and are incapable of defence without on their own part, they naturally must disappear from the seas. That does not apply at all to the use of iron-clads against navies in particular localities, or for many other purposes. I am quite aware of that. My object is not at all to give a bias against the proposal, but to elicit if possible from naval men how far the adoption of such a suggestion would tend to limit the use of iron-clads at sea. I confess I am disposed to concur almost absolutely with the general tenor of Mr. Barnaby's Paper, and should like to congratulate him, and also the Members of this Institution, upon having had so able and suggestive a Paper put before them as the first instalment this morning.

Mr. J. Scott Russell, F.R.S. (Vice-President): I would only add one other voice to the approbation with which Mr. Barnaby's Paper has been met. I confess that Mr. Barnaby has removed from my mind a great load of care and anxiety, because he has proved to me that many of the most difficult points, which I feared were not being grasped by the authorities, have been grasped by the authorities, and are now under their consideration. They no longer can say that technical men have not made up their minds, and do not know what to do next, and it is quite plain that there remains now no hindrance to our having a good fleet except having the will, and finding the money, and setting about the work immediately on the plan of Mr. Barnaby. We can delay year after year if we like, and amuse ourselves year after year if we like, but here is a plan that wants nothing but the will and the money. The first technical point which I consider of enormous value is the thorough consideration now given by Mr. Barnaby and his colleagues, not to water-tight compartments in the common sense of the word, but to water-tight compartments so organised as to preserve all the vital portions of the ship from serious injury, and while leaving certain parts unavoidably exposed to injury which cannot be prevented, limiting that injury. There is one point I would add. I would entreat Mr. Barnaby and his colleagues to consider more and more a question which I have had very much to consider, whether they would not carry their system of compartments a good deal further than they have yet carried it, and whether they would not make one or two water-tight iron decks, and whether they would not make the construction of the ship mainly mechanically to consist of plates forming water-tight compartments. He has already gone so far in that direction, that I am sure he will go as much further as is consistent with the circumstances, and I say I trust to that in the future for greatly improving the safety of our ships. The other point for which I think Mr. Barnaby deserves great credit is the manner in which he has developed that large question that a ship is not a fleet, and that a dozen of ships is not a fleet, and that a dozen of the strongest ships is not a fleet, and that nothing is a fleet but a series of ships of different classes, all grouped around some other ships, and each performing some special function of its own in that service. All the best naval men I know in all countries are of that opinion, and if only now we can get half a dozen classes of ships organised which are essential to form the fleet, then we shall begin to feel some confidence in our naval service, and this is an admirable preliminary to that. I return Mr. Barnaby my most heartfelt thanks as an individual, as a shipowner, and as a patriot, for the light he has thrown upon this subject. I feel that he has done us great good by making it public, and I hope the effect of his Paper will be that we shall have the fleet he has painted very soon made a fleet in actual iron and steel.

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Mr. CHARLES LAMPORT: I think it impossible to discuss at this time the advantage of any particular ship apart from the policy under which that ship shall be used in time of war, whether for coast defence, blockading, or cruising. Mr. Barnaby has laid down a principle of combined action which I think correct. Mr. Reed controverted it, and from his point of view I think with great force, but I may venture to ask him whether the time for pitting fleets against fleets on the broad ocean has not passed away with wooden ships, and whether or not, if Mr. Barnaby's proposed congeries of vessels were employed for the purpose of defending these shores in our narrow seas, the whole of the component parts of those congeries could not easily be kept together so that they might work in unison and without difficulty. So much for the policy as regards a combined fleet. Sir Spencer Robinson says that at the Admiralty there is a great want of decision; they do not know what to do; but I will venture to suggest, that although there may be some disadvantages in not knowing what new ships to begin or what change to make in ships which are being built, still more difficulty and still greater mischief arises from the want of decision in not stopping ships that have been begun under a bad system, or a system superseded, and in still spending thereupon the money of the country, instead of at once facing the loss and minimizing it by dismantling partially-built hulls. I think if that were done with decision we might save a great deal of money. Sir Spencer Robinson says that this indecision affects also the construction of torpedoes; and I suppose he also means, and no doubt he said so, although probably I did not catch it, that it applies also to the vessels from which these torpedoes are to be launched and put in action. Now I venture to state, that the torpedo is not like an iron-clad which may take years to build; I also say further that torpedoes can be constructed in days, and if it is a question of building ships to be used with torpedoes, I believe that in time of war if we were unprepared, and if it were necessary to use them, our private builders could construct a fleet of those ships within, if not weeks, at least months; and that therefore the danger arising from want of decision in reference to this part of our means of providing for future warfare need not weigh heavily upon the public mind. We have three things to look to. We have, in the first instance, to defend our shores, and I think torpedoes under all circumstances might defend them and prevent the landing of an enemy. We have, hardly second to this, but still second, to protect our commerce over the seas of the whole of the world. I think we have the solution of this difficulty in the unarmoured ships about which I have no doubt we shall hear something by and by from Mr. Brassey. Then comes this question, what are we to do with these huge iron-clads which are finished, and those which were commenced some seven or eight years ago, and about which we are still discussing whether this or that use is to be made of them? Is not the public mind, as well as the naval mind, undecided as yet what we are to do with them when we get them afloat? It seems to me, however, if we have torpedoes for defence, that inaction is the best policy until we really know what are the best means of concentrating our efforts. If we have a fleet of unarmoured ships swifter than any others, and carrying a single gun equal to the guns of ships of any other nation, we have in those two elements a solution of the present difficulty, and can afford to wait for the ship of the future.

The PRESIDENT: Before I call on Mr. Barnaby for a reply, I should wish to express in the briefest possible terms how cordially I concur in the complimentary language which has been applied to Mr. Barnaby's Paper. I have been very much struck by the terse, concise, and clear manner in which Mr. Barnaby, in really a very brief Paper, has given us a large amount of most valuable information.

Mr. BARNABY, C.B.: I generally regard myself when I come here once a year as putting myself into a sort of pillory. I remember last year that I was somewhat hardly treated, and also the year before, and it

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is quite novel to me to find myself in a position where so many people agree with what I have said. I must say that nothing could have given me greater pleasure than the adhesion of Sir Spencer Robinson to the view which I have laid before you this morning, and for this reason, that I do not think there is another man in England whose judgment is so valuable on all the points that have been raised. It is, however, with regard to Sir Spencer Robinson's remarks only that I propose to say one word. He has said that we are not building torpedo vessels. I wish to say that I attended the other day the launch of a ship built specially and solely for torpedo service for a Foreign Government for the discharge of Whitehead torpedoes. I say that England is so rich in ships that she does not need to build such ships as the *Zieten* at all; she can find, in the hands of private owners, ships that are every bit as good for discharging the Whitehead torpedo as that ship which was built especially for that purpose. Therefore, although the Admiralty have not built any special torpedo vessels; if they have—I do not say they have—a sufficient number of the Whitehead torpedoes themselves, England can do all the rest, and there is no good reason for our putting ourselves into a state of anxiety or trouble about it.

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ON UNARMOURED VESSELS.*

By T. Brassey, Esq., M.P., Associate.

[Read at the Seventeenth Session of the Institution of Naval Architects, 6th April, 1876; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

It is as a Member of Parliament, deeply interested in the Navy, and not as a naval architect, that I have been invited to read a Paper before this Institute; and it is from an administrative and not from a constructor's point of view that I shall endeavour to treat my subject. I shall accordingly break ground by laying down certain axioms, which, however familiar they may be, cannot be too constantly present to the minds of those who have to control or criticise the management of the Navy:—(1) There must be a limit to expenditure. Even when the nation may be anxious to vote lavish sums for the Navy, a wise statesman will deem it to be his duty to keep in check the impulses of patriotism; for he knows full well that a prodigal outlay on our part will probably arouse the jealousy of Foreign Powers, and lead to a proportionate expenditure on their own armaments. (2) The expenditure on naval construction should be devoted mainly to ships intended for the line-of-battle. The type will vary with the progress and the modifications of naval warfare; but, whatever the type may be, it is to the production of the most powerful fighting vessels that the resources of the Navy should be principally directed. We are not prepared as yet to throw off armour from our first-class vessels of war. Unprotected vessels, therefore, are of subordinate importance. They are required for the police of the seas and the protection of commerce; but I should consider it unwise on the part of the Admiralty to build a greater number of vessels of this class than are absolutely necessary in order to meet the demands of the Foreign Office for protection to British interests abroad. There must, of course, be enough vessels to furnish reliefs for ships coming home from foreign stations. Further than this we need not go in the construction of unarmoured vessels.

Before entering upon the special subject before me, I should like to advert briefly to another question—one of the highest importance—not, perhaps, suited for full discussion

* Received 27th March, 1876.

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on this occasion, but which has, nevertheless, a direct bearing on our policy in relation to the construction of unarmoured vessels. By the Treaty of Paris, England and France have entered into a solemn contract with the maritime world to respect private property, not being contraband of war, if carried in ships bearing the neutral flag. Is it to our interest to seek to abrogate the treaty into which we have entered? Our maritime trade being infinitely more extensive than that of any other nation, the area of vulnerability which we expose to attack is infinitely larger than theirs. On the other hand, our superiority in actual preparation for war to any probable, I might almost say possible, combination of nations against us is incontestible; while our unrivalled resources for the construction of the most powerful ships would give us the means of adding to our existing fleet with a rapidity which could not be equalled abroad. If, therefore, any future naval contest in which we may be involved is confined to the fighting ships on either side, and to naval operations directed against fortified places, we shall be the greatest gainers by the adoption of the new rule of international law. If these anticipations are correct, the necessity for the construction of the costly ships of the *Bacchante* type disappears, and we can devote to the building of fighting ships the money we have hitherto expended on unarmoured vessels. The large amount of that expenditure is the least satisfactory feature in our naval estimates, because, costly as they are, we are told by high authorities that we may not reckon upon our unarmoured ships as forming any essential part of our armed strength for war.

These considerations point to the policy of maintaining the smallest possible unarmoured navy, consistently with its efficiency for the police of the seas. For the training of seamen; for the purpose of exhibiting the British flag in foreign ports, and especially in the harbours of semi-barbarous Powers, who can scarcely realise the existence of a force unless it is visibly present to their gaze; for the repression of piracy and slavery, and for the punishment of offending savage tribes—we want, not *Inconstants* nor *Opals*, but the infinitely cheaper little vessels of the *Mallard* class. It is further to be observed, that we possess in the overwhelming superiority of our merchant navy in powerful ocean steamers, resources which are practically inexhaustible for the equipment of a fleet of unarmoured cruisers. This is another reason against a larger expenditure on unarmoured ships than the public service for the time being absolutely requires. The programme of shipbuilding proposed for the financial year 1876-7 seems wisely conceived with reference to all these various considerations. At the close of the last Session, the following return (*see* Table on next page) was presented to Parliament, giving a list of the vessels building or ordered to be built in the year 1875.

Further details with reference to the armoured and unarmoured classes are contained in a Parliamentary Paper of the present Session, from which it appears that, of the iron-

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clads, 8,037 tons are to be built in the dockyards, and 3,356 tons by contract; and that, of the unarmoured vessels, 5,460 tons are to be built in the dockyards, and 6,909 tons by contract.

Number to be built.	Type.	Guns.	Displacement.	Horse-power.	Cost.	
					Engines.	Hull.
					£	£
	Shah	26	5,700	1,000 nominal 7,500 indicated	55,000	173,000
3	*Bacchante*	16	4,000	5,250 ...	70,000	140,000
1	*Rover*	18	3,494	4,750 ...	64,000	27,000
2	*Sapphire*	14	1,890	350 nominal 2,100 indicated	25,550	49,000
6	*Opal*	12	1,864	2,100 ...	27,000	57,000
5	*Cormorant*	6	1,124	900 ...	12,000	37,000
3	*Daring*	4	894	120 nominal 720 indicated	10,000	26,000
2	*Arab*	3	620	95 nominal 570 indicated	10,000	30,000
1	*Pioneer*	6	499	80 nominal 480 indicated	9,400	11,500
6	*Mallard*	4	440	60 nominal 560 indicated	5,000	12,000
4	*Gadfly*	1	254	28 nominal 168 indicated	...	6,500
2	*Iris*	10	3,693	7,000 ...	...	10,000
2	Torpedoes	...	141	350 ...	6,751	10,000
2	Tugs	...	500	860 ...	15,000	10,000

There will thus be added to the Navy, in 1876-7, 23,762 tons, of which 11,393 tons will be armoured, and 12,369 tons unarmoured vessels.

While there is no great difference in the tonnage of the armoured and unarmoured ships to be built for the year, it is unnecessary to remind a professional audience that the number of tons affords no indication of the relative amounts to be expended on the two classes. The armoured ships will of course absorb a far larger sum than the unarmoured vessels.

I observe with satisfaction that the programme of the Admiralty includes no ship so large as the *Inconstant*. The designers of that vessel were betrayed into an exaggeration

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of size, from over anxiety to combine in a single ship every quality with which an unarmoured vessel can possibly be endowed. The *Inconstant* was to possess unrivalled speed, both under sail and under steam, and was to be armed with such a powerful battery of armour-piercing guns, that it was hoped that an engagement might be fought, even against an armoured ship, with some prospect of success. The attempt was ambitious, and not altogether unsuccessful; but the *Inconstant* must be admitted to be too costly a ship for the mere protection of commerce. "A perfect ship of war," as it was very prudently observed by the Admiralty Committee on Designs, "is a desideratum "which has never yet been attained, and is now further than ever removed from our "reach." Any near approach to perfection in the one direction inevitably brings with it disadvantages in the other. In the case of the *Inconstant*, the cost was such as to make it impossible to multiply vessels of her type in sufficient numbers for the protection of the great commerce which is carried on in every sea under the British flag.

The latest programme of the Admiralty shows that these considerations have been duly appreciated. The largest vessels now being constructed are the *Euryalus*, the *Boadicea*, and *Bacchante*, of 16 guns, 3,932 tons displacement, 700 nominal or 5,250 indicated horse-power, and costing in round figures £200,000. The cost of this class shows a small reduction upon the price of the *Inconstant;* and the vessels of more recent design exhibit a still more marked recognition on the part of the Admiralty of the necessity of keeping the cost and dimensions of unarmoured ships within reasonable limits. The measured mile speed of the vessels of the *Opal* class is estimated at 13 knots. They are armed with 64-pounder guns, and can carry coal enough to steam 2,680 miles at 10 knots, or 4,050 miles at 8 knots. The French ships of the *Infernet* type of 1,890 tons displacement, as compared with the 1,864 tons of the *Opal*, can steam, it is said, 4,000 miles at 10 knots.

Vast tonnage is not necessary in order to obtain high speed. The experience gained in the unfortunate example of the *Great Eastern* is conclusive on this point. Within certain limits, there is considerable economy in increasing the length of ships constructed to carry cargoes; but the same considerations do not apply in the case of ships of war. Cruisers for the protection of commerce would rarely be required to exert the full power of their engines, except in action, or in pursuit of an enemy. They would traverse the ocean and keep their station under sail; or, if under steam, they would proceed at the most economical rate of speed. By increasing the dimensions, a better result may be obtained for mercantile purposes with a given consumption of fuel; but economy of fuel is less important in a vessel of war, and multiplication of numbers is an important element of strength and efficiency. Recent experiments by Mr. Froude tend to prove

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that the dimensions of ships may be considerably reduced without loss of speed, and justify the view expressed by the Committee on Designs, that in every description of unarmoured vessel the smallest dimensions consistently with the attainment of the required speed should be adopted.

For European waters a large spread of canvas is not required. Hence a subdivision of the unarmoured class, as proposed by the Committee, would appear advisable, the one class being furnished with a considerable spread of canvas, while the other might be lightly sparred, and have sufficient engine power to attain a speed of 18 knots at the measured mile. The design for the *Opal* class seems to accord satisfactorily with the suggestions of the Committee for vessels intended to cruise principally under sail, and the new despatch vessels, the *Iris* and the *Mercury*, now being constructed at Pembroke, would seem to be a satisfactory class of swift and lightly-sparred vessels for the protection of commerce. The *Iris* and the *Mercury* have a displacement of 3,693 tons, and they are to be propelled by engines of 7,000 indicated horse-power. They will steam at the rate of $17\frac{1}{2}$ knots, or 20 statute miles, an hour, and their coal-carrying capacity will be sufficient to enable them to steam 6,200 miles at the rate of 10 knots, and 8,600 miles at 8 knots an hour. In the French vessels of the corresponding class, it is proposed that the coal supply should be sufficient for steaming 5,000 knots at a 10-knot speed. Until a recent period the limited supply of coal constituted the most serious defect of the English vessels.

It has already been pointed out that the small unarmoured vessels are growing more and more into favour with the Admiralty. The *Coquette* class has been highly approved in America. They draw 10 feet, are 125 feet in length, and are of composite construction. Their coal supply is sufficient for a voyage of 1,440 miles at 8 knots an hour.

Having now completed the enumeration of the unarmoured vessels in actual progress for the fleet, it affords me much satisfaction to be able to say that I believe the policy of the Admiralty in regard to shipbuilding has been devised by wise counsellors—men of rare experience, whether as sea officers or as naval architects; of whose talents the country has just reason to feel proud, and whose proposals deserve the support and the confidence of Parliament. The amount of expenditure proposed for the Navy must at all times afford, more or less, occasion for debate; and the subject will undoubtedly be discussed with anxiety in the House of Commons; but, as to the types—and this is what we have chiefly to consider at the Institution of Naval Architects—I venture to affirm that the recent course of the Admiralty merits our approval.

In addressing this Society I feel myself an interloper, but I have always appreciated the value of the Institution of Naval Architects very highly, and never more than since I have had the honour of a seat in Parliament; therefore I have felt it to be my duty

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to inform myself of naval opinions in regard to naval construction. The opportunities of gathering information are not very many, and I venture to say that those afforded by this Institution are among the most valuable and the most instructive which can be found. I come here entirely as a learner, and not as a teacher, but feeling very grateful to the Society for the good which it has done with regard to naval questions. I felt when I was invited to read a Paper before this Institution that if it did nothing else, it might perhaps serve to originate a useful discussion in which naval men might take part, and that, therefore, I had no alternative but to accept the invitation which I received.

DISCUSSION.

The Hon. Sir FREDERICK W. GREY, G.C.B., Admiral: My Lord and Gentlemen, I do not rise for the purpose of making any remark on the different types of unarmoured vessels to which Mr. Brassey alluded at the end of his Paper, but I wish to call attention to the administrative part of it. Mr. Brassey, in the beginning of his Paper, said that there were two axioms which ought always to be present to our minds, and one was that there must be a limit to the expenditure. That I think we all agree to, but the question comes, what is that limit? What would have been a very wise limit in the year 1830 would be an unwise limit in 1876; therefore it is impossible, I think, to lay down any strict rule upon that point. But that is not the point. The point to which I wish to call the attention of the Meeting is the second head: "The expenditure on naval construction should be devoted mainly to ships intended for the line of "battle. The type will vary with the progress and the modifications of naval warfare; but, whatever the "type may be, it is to the production of the most powerful fighting vessels that the resources of the Navy "should be principally directed. We are not prepared as yet to throw off armour from our first-class "vessels of war. Unprotected vessels, therefore, are of subordinate importance; they are required for "the police of the seas and the protection of commerce; but I should consider it unwise on the part of "the Admiralty to build a greater number of vessels of this class than are absolutely necessary in order "to meet the demands of the Foreign Office for protection to British interests abroad. There must, of "course, be enough vessels to furnish reliefs for ships coming home from foreign stations. Further than "this we need not go in the construction of unarmoured vessels." Now it is to this that I take exception. I maintain that that is not the rule that should govern our policy with reference to the construction of unarmoured vessels. It is, I think, undoubtedly our duty to keep up in peace time a sufficient force to enable us at the commencement of a war to put forth our strength in a way worthy of the country. Our standing Navy should be the nucleus of the larger force required in war. Whatever our reserves may be—and I am afraid they are at this moment very far short of what we should wish them to be—their efficiency in a war will depend upon the efficiency of our standing Navy with which they will be incorporated; that Navy now comprises only about 18,000 continual service blue-jackets, and yet small as that force is you have not cruisers enough to give them the practice afloat necessary to keep them efficient. Therefore I contend that there is a great fallacy in Mr. Brassey's Paper on that point, and when he tells you that you

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may limit the number of your unarmoured vessels to the number required for the protection of your interests, I think he makes a great mistake. I think that we ought to have a sufficient number of small cruisers and unarmoured vessels on all our stations to give full employment to our men, and particularly to the young lads on whom we spend so much money in training them for the Navy. We know at present that there are large numbers of these lads idling away their time in home ports. The First Lord of the Admiralty has told us that he has not enough unarmoured ships to meet the demands for reliefs abroad. We have not the means of giving employment to young captains and young commanders that we ought to have; and, therefore, in every way it is evident that our unarmoured fleet now at sea is insufficient for the purposes required. It is on that point that I differ from Mr. Brassey. This is no new opinion of my own. When I was taking part in the administration of the Navy at the Admiralty twelve years ago, I brought the question seriously before my chief, and pointed out that unless we did take measures to increase the number of our unarmoured ships and cruisers, we should be driven to the necessity of repairing old worn-out vessels in order to meet the demands of the day, and I appeal to our President to say whether that did not really happen, and was constantly happening for many years? I therefore maintain that Mr. Brassey is in error when he tells us that we can limit our unarmoured ships to the number required for the police of the seas. I have made these few remarks because, thinking the subject so very important, I did not like to pass it over.

Captain SCOTT, R.N.: I should like to make one or two observations, because it seems to me that Mr. Brassey, although he has done good service to us in calling attention to our Navy and mercantile marine, starts with a fallacy. That fallacy is, that we may remain until war actually breaks out, and then, by means of our merchant navy, and other means, be enabled to cope with any combination of Powers. The great point to this country is to preserve its trade; if we interfere with its trade, we at once cut off the sinews of war. Therefore, I maintain that what we have to do is to preserve our merchant vessels, and to keep them running just as they are in time of peace, in order that our food supplies and our communications with our Colonies, which are so important, be not interrupted. I may say, moreover, that, with regard to our merchant navy, I think the course that has been taken in drilling these men as reserves is admirable; but it is as reserve men to remain in their own vessels, and young captains to command their own ships; and in time of war these vessels should be ready certainly with the torpedo and light guns, and other means, which would make them able to resist any privateers that might attack them. I gather, however, from Mr. Brassey's Paper, that, in the opinion of the most eminent Frenchmen, they would leave our Navy alone, and would attack our merchant vessels. Our merchant vessels must be carrying in time of war munitions of war as well as food supplies, so that nearly every vessel would be liable to seizure. Of what use is speed unless, when the vessel is carried to the point she wishes to arrive at, she is able to fight?—and I think it is a fallacy to suppose that our cruisers are to be small vessels. A small vessel cannot possibly have coal-carrying power, which is the backbone of the whole matter. She cannot be a ram, which I hold that all these cruisers should be, and which our constructors are now making them; and she cannot carry the heavy guns which will enable her to compete with any vessel that may come against her; and, therefore, I think that there would be a great fallacy as to what Mr. Brassey says with regard to the smallness of our vessels, and what he has quoted, namely, that the smallest tonnage upon which speed can be maintained is the best. But what is the use of speed, as I have said, unless you have coal-carrying power to maintain it? You are not governed by that limit at all; you are governed by the coal-carrying power; you are governed by the attack, by the

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ram which you should be able to carry into action, and you are governed by the gun; and, therefore, it would be a great fallacy to build these small vessels that Mr. Brassey, I think, mainly advocates. Another point is, that our vessels are spread over the globe. Looking at the fact that they will be attacked by the navies of other Powers, which will endeavour to cut off our lines of communication, which would, of course, destroy us, it becomes a question not only whether our cruisers should carry heavy guns, but whether they should not, as some of the cruisers are now being built, be belted cruisers. I believe myself that is the direction we ought to take, and with a number of belted cruisers, carrying heavy guns, we should be at all times ready to withstand all the vessels of the world. I did not wish to speak on Mr. Barnaby's Paper, which requires very great consideration, though it is alluded to, and in a measure really bears on the present one, as to vessels round the armour-clads; but in my opinion, certainly every armour-clad, if not every ship of war, should have a proper counterpoise of the gun, the ram, and the torpedo, and, with that, sufficient small guns to keep off any attack of lighter vessels. I think without that combination no vessel of war can be considered perfect; and I think, moreover, that you require, if you have groups of squadrons, somewhat equal coal-carrying power, or means of coaling at sea, which we have not yet hit upon. Therefore I think that the vessels the Admiralty are now building, such as the belted cruiser, are the vessels required for our needs at the present moment, and which will enable us to maintain that supremacy which we have always held on the ocean.

Mr. E. J. Reed, C.B., F.R.S., M.P.: It is so great a pleasure to have the advantage of Mr. Brassey's views in this Institution, that I, for one, feel disposed to take all that he says in the best possible part, because I am quite sure he not only brings a very cultured and thoughtful mind, but a very zealous one, with regard to the interests of the naval service, to bear on these questions. But I wish to say a few words on this Paper; and, in the first place, I want to defend what I consider to be one of the finest ships in the world from unmerited depreciation on the part of Mr. Brassey; I refer to the *Inconstant* frigate. Mr. Brassey says of that frigate, that she "was to possess unrivalled speed, both under sail and under steam, and was to "be armed with such a powerful battery of armour-piercing guns, that it was hoped an engagement might "be fought, even against an armoured ship, with some prospect of success." I should like just to correct that statement to this degree, to say that she was intended to possess unrivalled speed under steam and to have a fair spread of canvas; but so far as I ever heard—and I was the principal designer of the vessel, under the guidance of distinguished officers who are here, and I am able to speak confidently on the point—there was no ambition whatever to obtain any excessive speed under sail, or to enter into any competition with other vessels under sail. With regard to the other point, about the armament, I wish to say that she had an armament of 12½-ton guns given to her. When Mr. Brassey says that the attempt made in this ship's design was ambitious, and not altogether unsuccessful, I beg leave to state that that is not doing full justice to the *Inconstant*. I wish to say that the *Inconstant* fulfilled actually, and more than fulfilled every object set before the designer of her in the preparation of the design; and I do not believe there is a single ship in the British Navy of which I have heard higher praise, for enormous speed under steam, for wonderful steadiness of gun platform, and for the due performance of all the duties that she was intended to fulfil. But I wish to say another thing about the *Inconstant*, and it is, that the *Inconstant* was not constructed without a very sufficient reason for her existence. It is very well for my friend Mr. Barnaby to give us general suggestions in his Paper, and most valuable; it is very well for Mr. Brassey to give us the benefit of his present cogitations on the subject; but there is one consideration superior to, and which always must and will outweigh the abstract thoughts of any of us, and that is the state of foreign navies; and I

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say that the *Inconstant* was designed—of her size, of her cost, of her length, of her horse-power, and with her armament and speed—expressly to compete with (and worthily to compete with) a very powerful class of American vessels, which was then under course of construction. There was a large number of very powerful and fast vessels indeed building in the American Navy. They were not successful—in the main they were very unsuccessful—although some of them met with a fair measure of success; but we could not afford, in this country, to wait and see whether they were to be successful or not; we had to produce a ship which would compete with them; and I say that that fact affords the very best possible reason that you could have for laying down any ship—namely, the existence of ships in other navies that we wanted to compete with and be superior to. Now there was a remark, which this Paper raises, which fell from our President, and I am very glad to have the opportunity of the incidental corroboration of the view which I am going to express which his speech furnishes. He spoke of unarmoured but heavily-armed ships. Now I wish to say that unarmoured but heavily-armed ships have been abolished in the British Navy, except in the case of the *Inconstant* and one or two vessels. The gunnery advisers of the Admiralty have persuaded them into believing, what I believe to be a most fatal error, namely, that unarmoured ships should not carry powerful guns, but are better armed when they carry a large number of weak and inefficient guns. I have before stated the fact that I believe that to amount to an absolute blight fallen on the naval power of this country. I quite admit that, for some purposes, the 64-pounder guns which are being put into our ships are valuable; but I say I view with the greatest possible alarm the fact that my honourable friend is able to state to this Institution—I do not know whether he did give the statement—that we are building ships to go 17½ knots an hour, with steel hulls and great coal-carrying power, and we are going to mutilate those vessels by putting into them nothing but 64-pounder guns. I know that, in making these observations, I have to work up against the opinion of some naval officers of considerable eminence; but I believe myself, the very advantage, the very superiority which we ought to secure for our ships of the Royal Navy, as compared with merchant vessels, is that our ships should be made fit to carry, and should carry powerful guns; while we know that unarmoured ships of the merchant navy should be made only to carry the lightest guns, in the event of their being required. I wish I could hope that anything said here would induce the Admiralty to reconsider their decision on that point, because I consider that that is one of the most fatal errors that has ever befallen a Navy like ours. Mr. Brassey says, in his Paper, that the coal supply was under-rated in ships until a recent date.

Mr. Brassey: The French claimed greater coal-carrying capacities for their vessels than we have given to ours until lately. Whether they were justified in that I do not know.

Mr. Reed: I do not believe in what the French claim, because I find in matters of speed, coal-carrying power, and other things, the French claim not only what is difficult but what is impossible, and I am sorry to say I am incredulous as to the impossible. But I do wish to point out that the coal supply question has been for very many years under the most careful consideration at the Admiralty, and we have had for a long time vessels in which large coal supplies form a very considerable item. Just to give an instance, take the case of the *Volage*. She has been at sea now for two or three commissions. That vessel carries such a large supply of coal, and is so efficient in other ways, that she was actually made to tow up the Indian Ocean two steam frigates, whose coal it was desirable to economise. We all know, also, that in the *Devastation* we gave an enormous coal supply as soon as we did away with masts, and we have received information that during the passage of His Royal Highness the Prince of Wales down the

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Red Sea, the other day, on his return from India, the *Raleigh*, a ship which has been occasionally brought under some imputations, distinguished herself by her enormous speed, and by the fact of her coal supply holding out far beyond that of the vessels with which she was in company. I say that these indications given by vessels, some of them a long time at sea, are extremely satisfactory. Now, on the general question, I wish only to add one remark. Sir Frederick Grey has spoken strongly in opposition to Mr. Brassey's view, and Captain Scott has practically done the same with regard to the limitation of the number of unarmoured ships. I want to say in support of Mr. Brassey, and in support of any views, however mistaken, that we may hold upon this question, that we are in a very unfortunate position—that the British public is, and that everybody is, from never being told what these unarmoured ships are wanted for in anything like detail. No information of that kind is ever put before Parliament or the country. This year, at a time when great pressure is being put on the country in order to build a quantity of additional unarmoured ships, we are still entirely without information as to what uses these ships are put to on foreign stations. I have not the smallest doubt that they are to be used for the best purposes, but we do not know. We can take up the *Navy List*, and see where they are, but that is all the information vouchsafed to us with regard to their employment. If some one of the gentlemen here, who are in the highest degree competent to give us that information, would tell us what are the demands made by the requirements of the service on the Navy for unarmoured vessels, they would greatly help us out of our present difficulty. Mr. Brassey's Paper is an extremely interesting, valuable, and suggestive one, but I think he will find that Captain Scott is right in saying that if you will have very small vessels you must have very inefficient ones. I go with Mr. Brassey to this extent, and I go with him gladly, that we are now in a better position than ever we have been in before for producing small vessels with high speed and good coal-carrying powers. Great improvements have taken place in materials, and ideas are changing very much, and I think that the Admiralty have shown us that a great progress may be made in that way, and if it were not for the wretched armament of the *Iris* and *Mercury*, I should say that in those vessels they have put before the world a type of ship of the most extraordinary character, and possessing immense speed, and every qualification that can be required on the part of very fast unarmoured vessels.

Sir FREDERICK GREY: With regard to what has been said, I may say that I think I should have no difficulty if I were at the Admiralty to-morrow, in telling the Chief Constructor what kind of vessels we require.

Mr. WILLIAM DENNY: Allow me to say a few words on Mr. Brassey's suggestion with regard to the employment of merchant steamers for war purposes. Although I am not fitted to speak on war vessels generally, yet I feel myself thoroughly well fitted to speak on this point; and I think that if the country trusts to the fast and speedy vessels of the merchant service for doing war service, they will trust to a broken reed, because I do not think it is within the power of those vessels to do it. They have great speed and great weight carrying-powers, but they are, every one of them—at least the best of them that are being built at this present moment—built to the very narrowest margin of stability; and I am perfectly certain that every person who knows the merchant service, and the large merchant steamers of the Cunard, the Peninsular and Oriental, the Royal Mail and other Companies, knows the fact that they are built with just the least possible margin of stability. Now on this account heavy guns cannot be carried in a fast merchant vessel even of a large size, because if they are carried these merchant vessels will simply capsize. That is I believe the point of the case. That is all I have to say—merely to direct attention to

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that one point on which the country will be deceived with regard to large merchant vessels. They are undoubtedly fine vessels, but they are built for a purpose, and that does not include a large margin of stability.

The Right Hon. EARL OF LAUDERDALE, K.C.B., Admiral: With reference to Mr. Brassey's Paper, it is my belief, in case of war, that we require a great number of unarmoured vessels to protect our trade. We should require thousands of them. Comparatively speaking, the whole seas are covered with our merchant ships, and without we have plenty of those unarmoured vessels, there would be the endless expense of building these large ironclads to look after our trade. The House of Commons, I think, would never find the money. The question is, whether we are to build a number of unarmoured vessels at present to protect our trade. People say we ought always to be ready with large vessels in a fleet for fighting men-of-war, but if we go to the great expense of building vessels that will protect our trade, they must be fast vessels, and by the time they are wanted they will be out of date. You will find the merchant vessels protecting themselves. In former times all the trade was protected by men-of-war, they had no protection, they had no speed; but now it is just the reverse; the fast vessels that would take care of themselves are nine-tenths of them merchant vessels, and my idea of our policy is simply this, when a war is declared, we have nothing to do but to go into the market and hire all the fast merchant vessels, of which a great number would be thrown out of employ, and then they would protect their own trade. It is like the vessels that we made letters of marque, in the late war, and privateers. You have only to hire these vessels, and my belief is, instead of building an enormous navy of unarmoured vessels to protect our trade, that that would be much the quickest and the cheapest way of doing it. Of course if there was a war, merchant vessels would have to go in batches under convoy; they would not cover all the seas, but they would have to collect together from the different parts of the world and be convoyed by men-of-war. My opinion is you would in the simplest way possible by that means get the means of protection for them ready-made to your hand. I believe one of the greatest questions of the present day is how are you to get men to man them when you want a number of these vessels, because the men will not come to the Navy now, and boys will not come: they would rather go to the merchant ships, because they give them better pay. That will be a very great difficulty before long.

Sir R. SPENCER ROBINSON, K.C.B., F.R.S., Admiral: There is one observation I should like to make, which perhaps would be better made before the House of Commons than here; still I should wish to make it. Mr. Brassey, in the very interesting and able Paper which he read to us, refers to the Treaty of Paris, and Captain Scott in dealing with the question had evidently the Treaty of Paris in his mind. I want to say a word upon that. The Treaty of Paris, as you know, makes enemies' goods safe under a neutral bottom, and it has been thought by many that a neutral bottom covering enemies' goods in this way procured to this country an immense advantage. It is quite clear *prima facie* it may be so, because the goods you want to send all over the world, on which our commerce depends, might be, if not contraband of war, carried safely in neutral bottoms; and it might be, although I know very well that there would be considerable difficulties, that the whole of the British merchant ships might find it desirable to put themselves under foreign flags, and carry on their commerce as they did before. I refer to this because Mr. Brassey, in his able Paper, mentioned this as one of the reasons for not keeping up a large force of unarmoured vessels. As I think with Sir Frederick Grey, Captain Scott and others, that a large force of unarmoured ships of war is, at any rate, essential for the due supremacy of this country on the seas, I wish to point out one objection to the view that Mr. Brassey has taken of the effect of the Treaty

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of Paris on our merchant shipping. You must remember that contraband of war in the neutral vessel will not be safe, but will be liable to capture; and therefore all our supplies of provisions—as to coal, you know the law as well as I do, it is not yet a decided question, but whether it is contraband of war or not it would be made so without any doubt whatever—coal, provisions, and gunpowder, and those pleasant little things torpedoes, and all the various inventions for sending us into the other world, would all be contraband of war, and we could not supply our distant regions with the facility, which probably occurred to Mr. Brassey and to others who have advocated this clause in the Treaty of Paris, that it appears at first sight we could. The only observation, therefore, which I have to make is this, that the impression Mr. Brassey desired to make, and very justly and very properly desired to make, that keeping up a very large force of unarmoured vessels of war was not required, owing to the effect of the Treaty of Paris, seems to me to stand only on one leg.

Sir FREDERICK NICOLSON, Bart., C.B., Vice-Admiral: Would you just allow me to say one word upon the point of what has been termed here the Treaty of Paris? I think that it is an erroneous expression to begin with; it never was a Treaty, it was only a declaration. There is one important point connected with it which we must not lose sight of, that the great maritime nation of the United States never agreed to it at all; they made counter proposals which were not accepted, and, therefore, so far as their trade is concerned, and I think that is perhaps the most important point to be remembered, they are not, and probably never will be, as matters stand at present, parties to that declaration. I call it a declaration because it is really only that and not a treaty.

Admiral WILLIAM HOUSTON STEWART, C.B.: There is a very important point on which Captain Hall is able to speak with reference to the observations that fell from Mr. Reed as to the arming of the *Inconstant*.

Captain HALL, R.N.: Some important remarks have been made upon the question of the armament of our unarmoured ships, and as I have given a good deal of attention to that subject, more especially to the armament of the *Inconstant*, in which ship I once served, I should like to make a few remarks on the subject. Mr. Brassey, if I understood him rightly, advocated the arming of our merchant ships. Mr. Reed, on the other hand, was opposed to that, on the ground that it is necessary in unarmoured vessels to have heavy guns, and that merchant ships are not able to carry them. I venture, with all due deference to Mr. Reed, to think that it is not necessary in unarmoured ships to have heavy guns, a large number of what are called light shell guns being in my opinion more efficient. I was always thankful I did not command the *Inconstant*, for I confess I should not have known what to have done had I met with an iron-clad. With such a powerful armament I should not have been justified in running away, and yet I could not have engaged with any prospect of success, for every shrapnel shell or common shell striking the *Inconstant* in any part, would have wrought fearful destruction, and striking at the water-line would have sunk her in a few minutes; whereas the Palliser projectiles fired from the guns of the *Inconstant*, would not in the same time do material injury to the iron-clad. The *Shah*, built since the *Inconstant*, has been armed with a larger number of lighter guns, and if any gentleman will compare the broadside of the *Shah* with that of the *Inconstant*, he will find that in a given time the former ship can fire a greater number of common shell, carrying a much greater total quantity of powder, or a greater number of shrapnel shell containing a much larger number of balls; and he will, I think, be inclined to come to the opinion that the armament of the *Shah* is more efficient when that ship encounters an unarmoured vessel than the armament of the *Inconstant*, and that neither ship has much chance of success against an

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iron-clad. If it be the fact that merchant steamers are unable to carry heavy guns, and I think they are unable, then those who advocate the arming of merchant steamers with guns must confine themselves to a limited number of light guns, as such vessels cannot carry more than a certain weight. Heavy guns necessitate a large amount of machinery to work them, and it seems to me as a general rule, that guns worked by machinery should only be put on board ship in small numbers when they are behind armour. When they are not protected by armour one common or shrapnel shell may disable the gun. On the other hand the same weight of armament, but made up of a larger number of lighter guns, would it seems to me be much more efficient and less likely to be damaged, and in a given time would do more harm. I therefore venture to think that the assertion that a blight has fallen on the Admiralty with regard to their mode of arming our unarmoured vessels is not correct.

Mr. REED: Allow me to say just one word of explanation. I should hardly like to be misapprehended, and Captain Hall has misunderstood what I said about the merchant vessels, at any rate. What I said was simply that you could not put heavy guns into merchant vessels, and that the only unarmoured vessels—that is to say, that could carry heavy guns—would be the naval vessels. I am quite aware of the view that he states, but I think I may draw from his speech this inference:—The *Shah*, which he has compared with the *Inconstant*, is now appointed, or is to be appointed, as we are informed in Parliament to the South Coast of America. There the *Shah* will encounter a number of little trivial iron-clads, as regards both guns, thickness of armour, speed, and every other quality; and I have listened with pain to the argument from naval officers that they would rather go and command the *Shah*, in which they must of necessity run away from such vessels, than the *Inconstant*, in which they could sink them.

The PRESIDENT: I should be very sorry to interrupt any one who wishes to speak on this subject, because my only desire is to promote the objects of the Meeting, and to get on with our business; but I cannot express the thanks which I think the whole of the Meeting will accord to Mr. Brassey for his Paper, without, in the first place, expressing my sense, in which I know many of you will join me, of the patriotic and able manner in which he devotes himself to these subjects. I think he is entitled to very great credit; and, therefore, it will really be to me a matter of the greatest regret if I find myself, on any important issue, to any extent differing in opinion from Mr. Brassey. But I must say, that I should be sorry if the influence, which a Paper from Mr. Brassey would inevitably have in all quarters conversant with these matters, was to be exerted in the direction of any serious discouragement of building unarmoured ships for the service of the British Navy. My own belief—and I am happy to find it confirmed by some of the ablest authorities who have spoken to-day—is that it is most desirable that the naval power of England should be supported by a great force of unarmoured ships; and I must say, with great submission to those who have expressed a different opinion, that I adhere to the opinion which I ventured to throw out in my Opening Address, this morning, and which I am happy to find confirmed by Mr. Reed, that, in my humble judgment, it is desirable that these unarmoured ships should be heavily armed. But I am in great hopes, if there is any difference of opinion between Mr. Brassey and myself with regard to unarmoured ships, it is not of any serious extent; because I find Mr. Brassey saying that he "should "consider it unwise on the part of the Admiralty to build a greater number of vessels of this class than "are absolutely necessary in order to meet the demands of the Foreign Office for protection to British "interests abroad." Why, Gentlemen, there Mr. Brassey raises the whole question. We do not any of us want to build unnecessary unarmoured ships. Then Mr. Brassey again, in a subsequent passage in his Paper, says, "These considerations point to a policy of maintaining the smallest possible unarmoured

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"Navy, consistently with its efficiency for the police of the seas." There again you raise the whole question. We do not want useless vessels, but we do want to maintain the police of the seas; we do want to protect the commerce of England. That raises the serious question, whether or not, in the event of war with a maritime power, the protection of our commerce would not imperatively require a sufficient force of unarmoured vessels; and I hope that I may trace in these expressions of Mr. Brassey that it really is difficult to find a point, if there be one, where he and I would diverge; because I do not contend for any unnecessary amount of unarmoured vessels, but I do contend for such an amount of unarmoured vessels as may fully and fairly attain those great public objects which Mr. Brassey himself acknowledges to be necessary. There is one other point on which I cannot help, after these Discussions, saying one word, which was referred to by Sir Frederick Grey, and that was Mr. Brassey's first point, that there must be a limit to expenditure. That is perfectly true; and, therefore, while I admit most broadly that it is for a great maritime power like England to set the example of grand experiments in every direction which can extend or increase our naval power, at the same time—and I hope none of my friends here will take exception to what I say—I do want to see that great expenditure of England not thrown away in useless experiments, but devoted to the building of ships. I want to see ships, and not monsters built. I hope I shall not give offence to anyone who hears these expressions, but I must say that my desire is to see ships built; and there is a phrase which has lately obtained on these subjects, which is a new one in nautical matters, which fully describes the character of vessels that I think we all should wish to see. We used to hear of good sailing ships, and good ships of various kinds, but there is a new phrase grown up of "sea-keepers;" and I do hope that the Admiralty will consider the necessity of maintaining a class of vessels of such a strength that they shall be sea-keepers, and able to keep the seas; because when we look at that vessel which will be discussed presently, with every wish to pay full respect to whatever merits it may have, and when I see such vessels as the *Devastation* and this vessel are costing huge sums of money, I cannot help feeling that those sums of money might be devoted to objects which would better insure our naval power, namely, the building of sea-keeping ships. My own belief is this, that you may build sea-keeping ships which, while they may be enabled to do good service on the ocean, will be equally available when brought home to our coasts to protect those coasts, and thus answer both purposes. I could not refrain from throwing out these observations, but my wish is to see unarmoured vessels to a sufficient extent, and that the vessels on which we are spending huge sums of public money should be vessels available for the defence of England in all places and under all circumstances.

Mr. Thomas Brassey, M.P.: My Lord, with your permission I will say two or three words in reply to what has been said. I am very much obliged to Lord Hampton for the interpretation which he was pleased to put upon my Paper. He has rightly appreciated the policy which I ventured to recommend in the Paper which I have read. I do not at all desire that our unarmoured fleet should be inadequate to the requirements of the country; but I do say this, that, in looking to the future, and making a provision for our future requirements, I think that our leaning should rather be to vessels of whatever type is recommended to us by the naval men for fighting purposes, than to vessels the use and value of which is limited to the protection of our commerce. There must be present to the minds of everybody who considers these subjects, whether in or out of Parliament, the conviction that every vessel that you build in anticipation of a future want, immediately imposes on the naval estimates a very considerable burden for the repairs which are necessary to keep that ship in order. All admit that it is a regrettable feature in our naval expenditure that so large a proportion of the money which Parliament liberally and cheerfully

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votes, goes not to the creation of additional naval strength but to the maintenance and to the repair of the ships which already exist. I say, therefore, that I would limit the number of unarmoured ships to the immediate requirements of the service, and so reduce the serious charge for repairs which the construction of those vessels involves. With regard to the training of our seamen, a consideration which Sir Frederick Grey put before us, and the value of which I am sure we must all appreciate, I venture to throw out this suggestion with great deference. I wish very much that we could go back, for mere training purposes, to vessels which should be purely sailing ships. I do not mean to suggest for one moment that there should be many such vessels in the Navy, but when I look to the valuable use to which brigs have been applied during the past winter in training the ordinary seamen of the Navy, who would otherwise have been spending their time on board the *Duke of Wellington*, and other stationary vessels, I am perfectly convinced that we should carry that plan a little further, and that it would be an exceedingly valuable addition to our vessels for training purposes, if one or two sailing tenders were attached to each of the largest sailing ships in our home ports. I believe by that means you would keep your young sailors and young officers much more at sea than at present, and at a much less cost than is now incurred. Then, with reference to our position at the outbreak of a war. Sir Frederick Grey has very properly put before us the necessity of giving adequate protection to our commerce in such an emergency. For that purpose I venture to say that we may look, not without some confidence, to the resources afforded by our merchant service. It may be that the greater number of our merchant steamers are not available, but I should be very much disappointed, if, upon investigation, it was found that none were available. Anyhow we know this, that the subsidies to ocean mail services have been advocated, and granted freely and liberally by Germany, by France, and by the United States, especially the two former Powers, because it was thought by the Governments of those countries that if the time came, or the emergency arose, they would then be able to call upon those vessels to render valuable supplementary services for war. Surely, if we give our large subsidies to the great ocean companies, without seeing that the vessels so subsidised by our Government are at least as fit for war as the vessels subsidised by other Powers, we shall have failed to make use of a valuable source of strength. My honourable friend, of course, spoke a word of affection for his own child, the *Inconstant*, and I have to say to him that I would not pretend to enter into a controversy with a man of his eminence as a naval architect upon such a subject, in reliance upon my own unaided judgment; but when I look to the last Report of the Committee of Naval Designs, and to the evidence tendered to that Committee by Captain Waddilove, I am justified, if I may follow the captain of the *Inconstant* upon such a subject, in describing the results attained in the *Inconstant* as only in a qualified sense successful. And qualified in what way? Why in this way. The coal-carrying capacity was pointed to by Captain Waddilove as unsatisfactory, and why? Because the *Inconstant* at full speed could only steam 2¼ days. If the *Inconstant* is to be regarded as an ocean steamer for the protection of our commerce on the wide seas, I say that her coal-carrying capacity is not satisfactory. Then there is another point about the *Inconstant:* she is a very costly ship for the purpose for which she was designed. Bearing in mind, as we must do, that after all our naval expenditure is not an unlimited quantity, we are brought to this issue, are we to prefer one *Inconstant* or two *Volages*, or three vessels of an even more moderate size? You have to choose between the three alternatives. I do not recommend, either in this or in any other place, a smaller vessel than the *Inconstant* because I wish to spend less on the Navy, but because I feel it important that you should have as numerous a fleet as you possibly can, provided it be

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composed of efficient vessels for our protection; and I say that, unless Parliament is prepared to add very largely indeed to the naval estimates which they are now voting, if you spend all your money on unarmoured vessels of the *Inconstant* type, then you produce a fleet not numerous enough to serve the purpose which you have at heart. The value of numbers, I think, has been greatly commended to us by the Paper of Mr. Barnaby, for he has shown how much you may add to the strength of vessels like the *Inflexible*, by surrounding them with groups of tenders to protect them against the attack of the torpedo. That, again, I take to be a very strong argument in favour of building unarmoured vessels of as moderate a tonnage as is consistent with the purpose for which they are intended. I will not trespass further on the time of the Meeting, except to say that with reference to the controversy about guns, that in this, as in a great many other problems, a compromise is not an unwise solution of the difficulty. Why should not we have mixed armaments? I observe in the papers that mixed armaments have been strongly advocated by French officers of very great experience. They say, "Have some "armour-piercing guns," and as there is an advantage in numbers—not in ships, but with reference to guns—and as it is most conspicuous in a combat between two unarmoured vessels, let us have, in addition to a few armour-piercing guns, a number of guns of less power but sufficient for the penetration and destruction of unarmoured vessels. I believe if the Admiralty can adopt that view, and not be frightened by the idea of confusion in action by the difference of ammunition, and so on, that the plan of a mixed armament may be attended with advantage. I beg to thank the Meeting very much.

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ON CIRCULAR IRON-CLADS.*

By E. E. Goulaeff, Esq., F.R.S.N.A., Lieut. of Naval Architects, Imperial Russian Navy, Member.

[Read at the Seventeenth Session of the Institution of Naval Architects, 6th April, 1876; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

In venturing to address this distinguished professional Meeting, I am quite conscious of my own inability to deal with this subject in a manner which its importance deserves, especially after the excellent lecture delivered by Mr. E. J. Reed, C.B., M.P., in the Royal United Service Institution, and after what has been written by him previously to the *Times* on the subject. But I deeply wished that these present Meetings should not pass over without registering the birth, or acknowledging the development and the existence at sea, of such typical new vessels as the "Popoffkas," or the circular iron-clads of Russia; and it is only for this reason that I have with pleasure accepted the proposal to prepare a Paper for these Meetings.

It was in the beginning of the year 1869, that the idea of circular ships such as they are, or very little differing from what they are at present, was conceived by the distinguished Admiral Popoff, of the Russian Navy, and, having had the honour of working under him at the time, I can bear witness to the considerations which induced him to choose such circular form for the ships, which ultimately have become known by his name. It was chosen after many years of experience and study of the behaviour of the long ordinary ships at sea; after the careful study of the development of iron-clad construction, to which few persons have paid so much attention as Admiral Popoff did, and it has been chosen principally in consequence of the very important results obtained in this country by Mr. Reed, with his well-known broad and short ships, which superseded the narrow and long iron-clads of early date. Admiral Popoff argued that results of still greater advantage would be ensured if Mr. Reed's principle of broadening and shortening ships were followed still further, and therefore it is to this principle, which has been fully appreciated and mastered by Admiral Popoff, that the circular

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iron-clads owe their existence. It is the continual consideration and analysis of the results acquired with such ships as the *Pallas*, *Bellerophon*, *Hercules*, and others, that induced Admiral Popoff to broaden all the ships of his own design, and to decide as early as in the year 1868, the breadth of his ship, *Peter the Great*, as 64 feet, in order to supply her with the power of carrying 40-ton guns and 16-inch armour—unprecedented until then. Lately, with the same ideas in view, the Admiral has proposed plans for broadening the existing narrow and weakly-armoured ships, built during the earlier period of the iron-clad era, by cutting them longitudinally along the plane of keel, separating the two halves, and inserting between them a new portion of the bottom, thus being able, with a very small additional weight of hull, to get very great additional displacement for carrying guns of the increased size, and additional layer or layers of armour. These plans were exhaustively discussed by Admiral Popoff with Mr. Reed, and when the reconstruction of old iron-clads into ships equally powerful with modern ones may be found necessary, Mr. Reed will be able to bring these plans forward, and apply them to practice better than anybody else. My object in mentioning this here is to give additional proof that circular-ship construction, as well as many of Admiral Popoff's other labours, were based mainly upon Mr. Reed's principle of broadening and shortening ships, and that the circular form is the development of that principle to the extreme limit.

One of the most important conditions for the defence of the Black Sea coasts limited the draught of the vessels to about 13 feet. The only then existing type of vessel which fulfilled this condition was that of unarmoured gunboats, since any armoured ship, if built of ordinary form, and if designed to carry heavy guns and thick armour, required much greater immersion. Unarmoured gun boats, however, were not considered efficient, because a single shot from an insignificant gun is sufficient to penetrate their sides and sink them with all hands on board. Therefore an entirely new class of vessel was requisite to admit of the heavy guns and efficient armour protection, combined with the very small draught of water. To satisfy those conditions, no type of vessel could have been better adopted than the circular, because with no hull of any other form and of the same weight could so great a displacement upon the same draught of water have been obtained.

The head of the Navy, His Imperial Highness the Grand Duke Constantine, with his usual wisdom, appreciated the value of such considerations, and accordingly two circular ships of 96 feet in diameter, and 12 feet 6 inches draught, were ordered to be built. The displacement which such small dimensions gave has yet enabled them to carry two 28-ton guns mounted in a turret, protected, as well as the sides at the water-line, by armour equivalent to 11 inches in thickness. They were meant strictly for

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coast defence purposes, and, therefore, no great speed was required from them. They have open turrets, because being intended for the defence of certain narrow straits and entrances they can, when in action, occupy positions behind some defensive protection, such as submerged torpedoes; and, when attacked, can choose their own distance from the enemy, placing themselves always beyond the reach of rifle-fire. The precision of firing from guns so mounted, and other reasons, have settled the adoption of open turrets on board these circular ships.

The form of these vessels is sufficiently illustrated by the diagrams (Plate I.) and the model, which by the kind permission of the Lords of the Admiralty I am able to bring before your notice; the curvature of the bilge being the arc of a circle, and the

	Novgorod.		*Admiral Popoff.*	
	Feet.	Inches.	Feet.	Inches.
Extreme diameter	101	0	121	0
Diameter of flat bottom	76	0	96	0
Depth in hold at centre, from underside of beam to top of the frames of the double bottom	13	9	14	0
Draught of water — Forward	13	2	12	0
Draught of water — Aft	13	2	14	0
Draught of water — Mean	13	2	13	0
Height of barbette tower from load water-line	12	0	13	3
Diameter of barbette tower outside	30	0	34	0
Height of upper deck at side, from load water-line amidships	1	6	1	6
Displacement in tons	2,490		3,550	
Area of midship-section in square feet	1,170		1,416	
Engines, nominal horse-power	480		640	
Coal supply in tons	200		250	
Propellers, screw, in number	6		6	
Complement of officers and men, number	110		120	
Armament, breech-loading guns two in number, each weighing, in tons	28		41	
Smaller guns in unarmoured breastwork	...		4	
	Feet.	Inches.	Feet.	Inches.
Height of armour on side above water	1	6	1	6
Depth of ditto below load water-line amidships	4	6	4	6
Thickness of armour on sides (including equivalent thickness for the hollow iron girders behind armour) upper strake	0	11	1	6
Ditto lower strake	0	9	1	4
Ditto on barbette tower	0	11	1	6
Thickness of deck plating	0	$2\frac{3}{4}$	0	$2\frac{3}{4}$

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bottom flat. During the construction, the dimensions of the first ship completed, the *Novgorod*, were slightly modified by sheathing the outside iron skin and the side armour with wood and copper, and this has brought the dimensions of the ship to those which are given in the Table.

The guns, mounted in the *Novgorod's* turret, can with their carriages revolve completely round, and the carriages are so constructed as to admit of each gun being trained independently of the other through a certain angle. The height of the breastwork, or turret, entirely covers the men working the guns. The upper deck outside the breastwork is heavily plated.

These are the chief points of the design of the *Novgorod*, to which I consider it necessary to draw your attention. From want of time it would be preferable to pass over the description of the details of construction, as these have been given fully enough on several previous occasions. I will glance only hastily at one more important feature peculiar to that ship. I refer to the arrangements of engines and the way of working them.

There are two isolated boiler rooms, containing four boilers each. These supply six engines each of 80 horse-power (nominal), compound, horizontal, working each an independent screw of 10 feet 6 inches in diameter. All the shafts of the screws are parallel to each other. The pitch of the screws varies according to their positions: beginning from the screw nearest to the middle of the ship, on each side, their respective pitch is 10, 11 and 12. These were found to be the most advantageous, according to carefully-conducted trials. Steam from each set of boilers is conducted into a separator, and from there it is distributed between the engines. There is one engineer for each side of the engine room, and both of them are stationed on a common platform upon which the starting and reversing gear, &c., for all the engines are fitted. Voice-pipes from above are led to this platform to transmit the captain's orders. The engines are supplied with Hearson's strophometers, so as to show at any moment the number of revolutions which each engine is making, and to regulate the uniformity of the speed accordingly.

The *Novgorod* was launched and completed in 1873. From that time her qualities at sea, as proved by her cruising over several thousand miles along the coasts of the Crimea and farther east across the open sea direct to the Circassian shores, have been found to exceed all expectations. She visited all the ports of the Sea of Azov, into which no iron-clad in existence, carrying the same guns, and having the same protection, could enter. Only in her earliest voyages was the *Novgorod* attended by a steamer; since her qualities were ascertained she has been always entrusted alone at sea, as any

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other ship would be. During that period several alterations have been made in order to make this coast defence vessel able to contend, when necessary, with any seas she may meet. For instance, her natural ventilation has been so improved, that now the ventilating fans are taken out, and when the ship is steaming, even in a heavy sea, with all deck hatches closed, the draught is maintained by the great volumes of air which enter through the big shaft or tube placed in the centre of the vessel, and partly through the perforated bottom of the turret. Her anchors are now worked from the top of the bow superstructure, thus ensuring perfect safety when the vessel is riding at anchor in the open roadsteads. I may state, in passing, that while I was planning under Admiral Popoff's instructions the arrangement of this alteration on board the *Novgorod* the waves swept alternately the low sides of the ship. Yet they produced scarcely any effect upon the vessel. I was able to work comfortably with the drawing instruments, so unnoticeable was the rolling. All boats are now taken up on the davits, instead of being left on the deck, where the sea might injure them. Such are the most important of the many arrangements introduced, since experience has been acquired with this new vessel at sea, to ensure greater comfort of seaworthiness, and this experience leads to the belief that in future such ships need not be designed merely for coast defence purposes. The under-water part of the bow is fuller than that of any other vessel, and consequently it possesses enormous buoyancy. Owing to this buoyancy, increased by the existence of the bow-superstructure above the deck, and owing to other results of her extreme proportions, the ship has a constant tendency to ride over the waves, behaving much in the way that a duck would, and not penetrating through the water like a long and narrow ship. Her stability is immense, and her steadiness as a gun-platform is greater than that of a ship of any other form. Owing to the great beam, low freeboard, and perhaps also to the flatness of the bottom, the rolling of the *Novgorod* is very limited indeed, and it seems to me that in the present state of the subject, instead of entering into the discussion of any theoretical hypothesis on the behaviour of a ship, whose resistance to rolling motion and other conditions are widely different from those of ordinary shaped ships, it would be preferable to state only that the greatest angle of roll which was observed while I had the pleasure of steaming on board the *Novgorod* for several days at sea, during the Equinoctial gales, never was such as to expose her lower edge of the side armour—the instrument for measuring the angle of heel showing at that time that the arc through which she was rolling was 6 or 7 degrees: and this was in waves in which ordinary ships steaming the same course as the *Novgorod* were rolling very heavily, so much so in fact that several objects on board were sliding down and falling in the cabins, whilst some curiously unstable candlesticks on board the *Novgorod* remained unmoved on the tables. The forward sharp edge of the superstructure breaks the tops of the waves when the

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ship is driven against a head sea, and some of the broken water is precipitated on the deck, but soon disappears from it, because of the great round up of the surface. Both the captain who commanded the *Novgorod*, and the officers who served on board of her, would only be too glad if they were to be sent to the Mediterranean, so confident are they in the sea-going qualities of their circular ship.

Much was said about the *Novgorod* steaming slow, but people compare her propelling power with that of the English ships, forgetting that Penn's engines develop occasionally more than eight times the nominal horse-power, whilst the engines of the *Novgorod* have unfortunately developed at sea as yet only about four-and-a-half times. The *Novgorod's* speed, had the engines been of the same efficiency, would have been nine knots; while there exists no ship in the world so small as the *Novgorod*, and carrying the same armour and guns even on a much greater draught. Therefore had this ship been built for other purposes she might have possessed a greater speed. Owing to the relative power of the engines, there is indeed remarkably little diminution of speed when such a ship is driven against the waves at sea. It has been argued that the screws of the *Novgorod* are left more unprotected than in other ships; but that is of no importance for her purposes, and could be easily altered by arranging them either in special inner tunnels, as I should recommend, similar to Mr. Griffiths' plan, or otherwise, should the purpose for which this vessel is designed be altered.

The improvements in torpedoes, and in their application, lead to the adoption of this formidable weapon in preference to the ram; but a ram can be fitted to a slightly elongated bow, and would be even more than usually effective in such a vessel, because of the advantage that the short ship always has in respect of handiness and manœuvring qualities. The multiplicity of screws affords a most powerful and effective means of governing the course of the popoffka, and of enabling her to be manœuvred really with wonderful ease. Owing to the multiplicity of engines, the *Novgorod* is much safer than any ship having a single or twin propeller, because of the diminished chances of losing entirely her mobility when in action.

The construction of the second popoffka advanced less rapidly, but this was due to the intention of improving her fighting efficiency, and of insuring more perfect armour protection. Accordingly, the diameter and displacement were enlarged to what it is shown in the preceding Table. That was easily done, because very little addition to the then completed double bottom of the hull was required. The very small addition of only 10 feet on each side of the vessel allowed the size of the guns to be increased from 28 tons to 41 tons each, to add to the armour additional 7 inches of solid iron completely round the vessel and the turret, making it now everywhere equivalent to 1 foot 6 inches,

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and to more than double the power acting upon each of the middle screws on each side. These two screws were consequently made larger, and their shafting lowered nearer to the inner skin of the double bottom; these screws being meant to increase the ship's speed while she is steaming in deep water.

The 41-ton guns in the turret of this ship will be mounted according to Lieut. Raskasoff's plan, which has been skilfully worked out by Messrs. Eastons and Anderson, engineers well-known in professional circles. By this plan the guns will be worked by hydraulic power, and will be lowered down to be loaded and aimed behind the protection of the thick turret armour. On each side of the superstructure, and within it, four smaller guns are placed, able to throw projectiles efficient enough to penetrate the sides of unarmoured vessels or gunboats and destroy them. These guns are above the reach of the sea. Being a bigger ship, the *Admiral Popoff* (such is the name of the second popoffka) is in every respect better than her first consort, and both in seaworthiness and speed she will surpass her. The ventilation of this ship is still more improved as compared with that of the *Novgorod*. The extensive superstructure affords accommodation for an admiral, captain, officers and men, as comfortable and light as on board the best broadside ship.

As we have seen, the service for which the existing two vessels have been designed admitted only a very limited draught. Not only that, but the diameters of these ships, too, were similarly restricted by the means which we possessed in the Black Sea for hauling up vessels in order to examine and make any repairs to their bottoms. The only dock which existed at the time when the building of these vessels was sanctioned, was the patent-slip, with two ways, for hauling up merchant ships of 1,200 tons, on each. This then settled the displacement of the *Novgorod*. The entrance to that dock is 120 feet wide, and that decided the enlarged diameter of the popoffka *Admiral Popoff*, with all allowances. Next year, when the new floating dock, on Clark and Stanfield's principle, is completed, there will be no such limitation to the diameter and size of the Russian popoffkas, as such a dock can be infinitely extended.

Not only the capability of carrying heavy guns and thick armour, or the sea-going qualities, or the speed of these vessels, but even the possibility of their flotation upon water, and their ability of steaming straight, were doubted by the writers to certain Russian newspapers who opposed Admiral Popoff in a most thoughtless manner during nearly a year; but, at the end they only proved the truth of the proverb: "A prophet is "never without honour, save in his own country." English papers have already given some due consideration to the subject, and, speaking now only as a naval architect, it may be hoped that the same thing will not be repeated here, and that Mr. Reed's persistent

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advocacy of extremely short and extremely broad vessels, the advantages of which he has so ably demonstrated in his lecture "On Circular Iron-clads," above referred to, will be listened to with more confidence and respect. As to Russia, this bold idea of Admiral Popoff's would not have been, perhaps, ever accepted and carried out, but for the great knowledge and remarkable foresight which has always distinguished the Grand Duke Constantine, the Lord High Admiral of Russia, who knew how to appreciate the enormous capabilities of the forces that recent discoveries, such as the introduction of iron and steam propulsion, have placed at the command of men, and the necessity for changes in naval construction consequent upon such changed conditions. Thus, following through the development of the Admiral's idea into the existing ships, we should find the untiring and constant encouragement, and assistance, of his Imperial Highness, and the gracious patronage of his Imperial Majesty himself.

We have seen that the two existing circular iron-clads were designed and built for special purposes. We have also seen that their diameters and draughts were very restricted. Now I will beg you to turn your attention to the great field which the adoption of circular ships of unrestricted dimensions is opening to those who care for the development of the most important quality of fleets, namely, their offensive power.

The constant increase in size of ordinary war ships, as shown by the progress of naval construction for the last seventeen years, has driven us into such dimensions and cost as would have been increditable before armour was introduced. And yet, these great efforts to increase the defensive and offensive qualities have resulted only in reaching 14-inch armour as the maximum thickness attained in a completely protected ship. Increased guns, ready to penetrate any such armour, have given birth to Mr. Reed's now famous design of a citadel ship; and, in my humble admiration of this great idea, as adopted by the distinguished gentleman who at present so ably fills the office of the Director of Naval Construction of England, and as embodied in the *Inflexible*, I feel confident that no bigger guns and no thicker armour can possibly be carried by any future iron-clad of the same displacement, if the same proportions of length to breadth be adhered to. With vessels of such size and proportions, though we are able to measure armour not by inches, but feet, yet such measurement is applicable to the protection of the so-called "*vital*" parts; and in the number of guns, even the *Inflexible*, like all previous heavy-turreted iron-clads, carries only four, mounted in two turrets.

Such, then, is the defensive and offensive power of the very best of all ships of what may be called the ordinary type, yet in existence; and therefore we may regard the armour, varying over the protected surface of a citadel and turrets from 16 inches to 2 feet, and four guns in two turrets, as the limits of the fighting and defensive power of an ordinary ship of 320 feet in length, and about 27 feet draught.

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But already we are perfectly sure that the progress of artillery will not end with the completion of an 81-ton gun, and a ship of the same enormous size and proportions would be able to carry on the same draught only two 160-ton guns, and perhaps none of the guns of the future, say, exceeding the weight of 500 tons each. The only course left to get means of carrying on any ordinary long ship, of any ordinary proportions, an additional number of turrets, to enclose a greater number of very heavy guns, would be to enlarge such a ship, and to make her length equal to 400, or 600, or 800, &c., feet, and the draught equal to 35, or 45, or 55, &c., feet, according to the number of guns required. "As to the excessive length," says Mr. Reed, "we know that in the only "great iron-clad action which has been fought at sea, a long and narrow ship, by her "incapability of turning round, brought discredit and disaster on the Italian Navy at "Lissa." Yet the ship referred to here was less than 300 feet long, although she was somewhat less than the ordinary breadth. The importance of smaller draught was remarkably well demonstrated by the passive attitude of the French Navy in the Baltic, during the last war, notwithstanding the superiority in number and power of the French ships as compared with those of the German Navy at the time.

Returning to the circular vessels, and comparing the *Novgorod* and the *Admiral Popoff* with any of the existing ships of whatever navy, carrying the same guns, and protected by the same armour, it will be evident at once that their size is remarkably small. For instance, in the English Navy we can compare the *Novgorod* only with the *Glatton*, in respect of armament and armour, but drawing more than 19 feet of water; and the *Admiral Popoff*, in size of guns and armour, has no rival afloat; yet the displacement of the *Novgorod* is only 2,500 tons, whilst that of the *Glatton* is 4,915 tons, and the *Admiral Popoff* is but 3,550 tons. Therefore we may regard these existing ships as capable of being enlarged easily to several times their present size before their lengths and draughts would exceed those which are already reached by ships of ordinary proportions. The following diagram is submitted to show the growth of power of the circular ships so enlarged, both in the direction of length and draught.

By the kindness of Mr. Barnaby, I have had the advantage of seeing, at Torquay, several most valuable experiments on the resistance of the circular models, conducted by Mr. Froude with all the precision and wonderful ability which have made him so pre-eminent and well-known, not only in England, but in Russia and elsewhere. In producing my diagram before your notice to-day, I venture to trust that, although the experiments are still incomplete, and, therefore, the results are not yet published, neither Mr. Barnaby nor Mr. Froude will have an objection to my introduction here of only one item chosen out of all those experiments. Upon this item, ascertained with the greatest precision—namely, the true amount of resistance offered to the motion of a

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model of a circular ship, 160 feet in diameter, and 13·7 feet draught, at a certain speed—I have based the whole construction of this diagram, being able with the help of Mr. Froude's "scale of comparison" to calculate precisely the indicated horse-power of engines necessary to drive each ship at a 12-knots speed, and to ascertain exactly the amount of coals necessary to keep the ship steaming during six days at that speed.

Increasing this 160-feet ship, both in diameter and draught, 1·25, 1·5, 1·75, and 2 times, I have obtained the upper curve No. 1 (Plate II.), representing the rate of increase of the displacement. Then, on corresponding ordinates, I have set downwards from the curve of displacement the number of tons to which the weight of engines and coal supply will amount for each ship, and that has fixed the second curve from the top No. 2. From the base-line I have set upwards, at the corresponding ordinates, the number of tons representing the structural weight: curve No. 4. Further, an approximate number of tons for each ship has been set upwards from the curve No. 4, to represent the weight of crew, provisions, water, anchors, cables, stores, &c., and thus curve No. 3 has been obtained. The remaining part of the displacement of each ship, represented by the parts of ordinates enclosed between the curves No. 2 and No. 3, is available wholly for armour and guns, with their carriages and shot and shell.

The truth of Mr. Froude's "scale of comparison" between the resistances and the corresponding speeds of the geometrically similar bodies moved through water is so well established that I need not refer to the calculations of the parts of the ordinates between the lines No. 1 and No. 2.

The curve of structural weights, No. 4, was drawn on the assumption that 22 per cent. of the displacement of each circular ship is taken up by the weight of her hull. This, at first sight, may seem rather a small per-centage to those who are accustomed to deal with ships of the present proportions. But the fact is that such a per-centage really does represent the structural weight of the existing circular iron-clads. These ships are both afloat, and have shown not the slightest degree of weakness. Their designer, Admiral Popoff, already considers them as heavily built, and is sure to reduce the scantlings of the iron in his next ships. It would have, perhaps, been reasonable for me to diminish this per-centage for the ships under consideration, which have been growing larger; but I feared that such a course might be looked upon as likely to lead to misrepresentation of the real state of the subject. Still, in adopting the method which I have followed, I felt sure that the structural weight would be less than it is shown and not in any case greater.

In speaking of the number of guns which constitute the armament of ordinary iron-clads, we have seen that the best of 320-feet long ships, drawing about 27 feet, is able to

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float only two 160-ton guns well protected, whilst the figures marked on the diagram in thick black, between the lines No. 2 and No. 3, show the number of 80-ton guns, similarly protected, which the circular ships, of the diameter and draught shown beneath the base-line, are able to carry; each turret capable of holding two such guns, or one 160-ton gun, and the citadels, in which these turrets are enclosed, being completely protected in all cases by armour, 1 foot 9 inches in the smallest ships and 2 feet in bigger ones, spread *uniformly* over the whole extent of the surface of the turrets and citadels, or castles, as we would call them in Russia.

From this diagram it will be seen that when a circular ship is made of such dimensions as to have the weight of hull about equal to that of an ordinary iron-clad, then, with the speed of 12 knots an hour, and with coals for six days' steaming at that speed, her offensive power would be doubled. With the same conditions as to the speed and coal supply, a ship 280 feet long and 24 feet deep will float six times greater number of guns; whilst a ship 320 feet long and 27·4 deep will have ten times greater fighting power as compared with the ordinary ship (the *Inflexible*). In this last, biggest circular ship considered, her forty guns might be mounted in twenty turrets, enclosed in a two-storied castle, protected as well as the turrets completely round by 2 feet of iron; the upper tier of 80 or 160-ton guns, firing at a height of more than 20 feet above water, and at a horizontal distance from the edge of the deck of about 100 feet, so that no sea could reach them. Yet such results are obtained without exceeding the length up to which the existing less powerful iron-clads have already grown. Thus the above-water target presented to the enemy's projectiles would be very nearly the same as that offered by an ordinary iron-clad carrying only two turrets. Owing to the still moderate draught, the under-water target presented by her to the moveable torpedo, or to ram attack, would be the same as the under-water broadside of an ordinary ship. Her handiness would be superior, because she is a short ship.

I will now attempt to show that speeds as high as 14 knots may and will be reached with circular iron-clads, provided only that the size is not too restricted; although even such speeds do not require the ship to be made as long and as deep as ordinary heavy ships are. For that purpose the line No. 2^{A} was drawn and obtained similarly as was the line No. 2, with the only difference that the indicated horse-power and weight of engines were calculated for a 14-knots speed; a similar very large coal supply, as in the case of 12-knots ships, was provided. True, the increased engine-power has taken more from the useful part of the displacement; yet, possessing the means of steaming at 14 knots continually during five days and nights, the circular ship of 240 feet length, and only 20·5 feet draught, will carry one and a half times greater a number of guns as compared with the most powerful vessel in the world. When the

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weight of the circular hull is about double that of an ordinary ship, she would float four times a greater number of guns; whilst when the weight of hull is about treble that of an ordinary ship, her fighting efficiency will be from seven to eight times the efficiency of an ordinary ship, with, too, a uniform protection by 2-feet armour, without any reduction. Therefore I consider that the highest speeds reached are compatible even with the purely circular form of popoffkas, and do not lessen their advantages in respect of armour and gun-carrying power as compared with long ships.

The above results are due not only to the increase, as the ships grow bigger, of the ratio which the part of the displacement available for armour and guns bears to that part of it which is taken up in shape of hull, engines, coals, &c., but also to the property of the circular ships that their citadels will be built mainly for the efficient protection of the guns, and not to create buoyancy; and to ensure the transverse stability: which both qualities, so extremely important for safety, would not be maintained in ordinary ships, had not the citadels been enlarged so much as not only to protect the battery of guns, but also to protect a good deal of the long narrow body of the vessel. The circular ship, in virtue of her form, already possesses great buoyancy, stability, and therefore safety, thus allowing the vertical armour protection to be limited entirely to the defence of the guns.

As we saw, at 14 knots speed, a large amount of displacement is taken up by engines and coals. Yet all that power may be distributed over a large area covered by the ship, and not confined to one single engine room, as is generally the case with ordinary ships. Dividing the power among many independent engines, similarly to the course adopted by Admiral Popoff in his first ships, the vessel would steam still with a good speed when as many as three, or even four, of those engines would be disabled or injured. Thus, if circular ships must be necessarily provided with powerful engines for reaching high speed, this, when in action, will prove to be one of their greatest advantages, as the ship will continue to hold her own, either in attack or defence, for an incomparably longer time than an ordinary one, which, with a disabled single engine or propeller, might very soon become the prey of the enemy.

I need not enlarge on the evident economy of propulsion, which can be obtained with steaming at reduced speeds, before such ships reach their destination, where battles are to be fought.

I have used in the calculations referred to only one system of protecting the guns, namely, the revolving turrets. I have done so because this system has been favourably looked upon in England, and is very familiar. I have thus been able to compare easily the capacity for carrying such turrets of ordinary and circular ships of the same

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speed. Such a system, however, would not be likely to be adopted in Russia. Breast-works, open at the top, and guns firing *en barbette*, worked by hydraulic machinery, have met with much favour in that country. With such a system, and with the same number of guns, the protection of 14-knot vessels would be from 2 feet 3 inches in a smaller ship to 4 feet 6 inches of armour in the bigger one, as shown on the diagram (Plate II.) by figures enclosed in circles for distinction. Whether that, or the system of mounting guns adopted in building up the Cronstadt or Spithead armoured forts, be applied, in any case the number of guns which may be mounted on board large circular ships cannot be compared with any of the ships existing, or in course of construction in any country, and may only be paralleled with the ordnance mounted in the fixed forts. But fixed forts require immense foundations, which prove to be extremely costly, and, notwithstanding their cost, sometimes weak. Besides, some points along the coasts, known to be of great strategical importance, have been so far left unfortified, because of the impossibility or difficulty of building such foundations. Finally, fixed forts are disadvantageous, simply because they are fixed. Whilst circular ships may be made not only as efficient for far less expense, but possessing the ability of moving, when necessary, with great speeds for long distances (ships above considered can steam a much greater distance than that between St. Petersburg and London, with their own coal), they may carry their destructive armaments to bear against the shores in the enemy's own waters, against any modern individual ship, or a fleet of such vessels at sea.

I have been increasing, as the ships were growing bigger, only the number of guns. To show how easily such ships can be protected with any thickness of armour, I shall have to quote the following—Admiral Popoff's own words:—"As the bottom is flat, the "increase of the immersion of the ship, by every two additional feet, gives power to "carry three more inches of armour, either over the whole extent of the deck, or over "the surface of the bottom." Therefore it may be seen that no form will lend itself more easily to the protection of the body of the ship against the fire of rifled mortars, or against the attack by fixed torpedoes.

I do not wish the proportions given with reference to the diagram to be accepted as perfectly precise, because in no case have I prepared an accurate design for every individual ship. But, as a large margin was allowed for other weights, I believe that still much greater offensive and defensive power than is shown on the diagram would be got out of each ship upon the dimensions considered.

Consequently, choosing out of an infinite variety of proportions which the diameter of the circular ships can bear to the draught, according to the given conditions, we can

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obtain ships, carrying any number of the heaviest guns and armour of any thickness within the limits of practical necessity, and yet not exceeding the draught of ordinary ships.

Such circular ships will be more economical than the existing ones of ordinary shapes, because from the adjoining Table we can see that, even at the great speed, the ratio

	Proportion of Weight of *Hull* to Weight of *Armour* and *Guns*, carried.	Proportion of *Engine-power* to Weight of *Armour* and *Guns protected.*
PARTIALLY PROTECTED SHIPS.		
Warrior	2·5 to 1	4·9 to 1.
Defence	3·0 to 1	3·5 to 1.
COMPLETELY PROTECTED SHIPS.		
Prince Consort	2·4 to 1	3·9 to 1.
Circular Ship—		
Novgorod	0·6 to 1	2·8 to 1.
Fast Circular Ships—		
"280 feet long"	0·5 to 1	2·9 to 1.
"320 Ditto"	0·4 to 1	2·2 to 1.

which the *cost of hull* of these vessels bears to the *cost of armour and guns* carried is very much less than in the case of ordinary ships, and also because the proportion of the *engine power* to the *cost of guns and armour* driven is also less. Therefore the circular form ensures the *true* economy. As another instance, I may mention the new design for a small unarmoured circular vessel able to carry two 41-ton guns, having the cost of hull and engines in proportion to each ton of weight of the guns *less* than in the ordinary unarmoured gunboats, carrying one less powerful gun.

But I should be unfaithful to the cause of "popoffkas" if I conclude this Paper without mentioning the following most important considerations:—

It has been proved in practice that Mr. Reed's 300-feet ship can be propelled through water as fast as a less powerful 400-feet vessel, and it has also been proved by careful experiments that a ship whose length is three times the beam can be made to go as easy, even with less expenditure of power, than one having the length equal to four times the breadth; therefore we must conclude that extremely short and broad

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vessels, approaching much more closely to the circular form than to the form of the present existing long ships—yet not quite circular—will do away with that increased part of the resistance which is due to the increased eddies appearing when a body of so comparatively abrupt an entrance and run as that shaped circular is driven through water. That has induced Admiral Popoff not to restrict his ships by the purely circular water-lines when higher speeds will be contemplated. Such moderate elongations of bow and stern, as were described by Mr. Reed, reducing the size of engines necessary to drive these ships, and consequently reducing their total displacement, and avoiding probably some other difficulties, arising, as Mr. Reed and Mr. Froude have suggested, out of the coincidence of period in ship and wave at high speeds, will promote the most economical propulsion at sea of the very heaviest guns protected by the very thickest armour.

Such ships, then—I mean those with slightly elongated bow and stern—could no longer be called "circular ironclads," nor would the name of "cyclads," or any other such term, be any longer available, but that of "popoffkas," which name was graciously given to this class of vessels by His Majesty the Emperor of Russia.

DISCUSSION.

Mr. J. D'Aguilar Samuda, M.P.: My Lord and Gentlemen, as to the Paper that is before us, I certainly am very glad to have the opportunity of expressing an opinion upon this matter, which has been rendered so interesting by the observations which have already fallen from Mr. Reed with reference to these vessels. But I would beg to say, that, with every disposition (which I am quite sure every Member of the Council and of the Institution has) to give the greatest praise which they possibly can to any subject so interesting and so novel, I think we should be wanting in candour, if we allowed a desire to give that praise to have any precedence over our convictions, when we feel we cannot reasonably or freely give it. With regard to this Paper, it appears to me that it may properly be divided into three distinct subjects:—the first and most interesting one, which gives us a clear description of that which has been done with these vessels; the second, which I venture to think is a purely imaginative one, as to that which may be done, and which draws conclusions as to speeds to be obtained with these vessels—to which conclusions, I must say, I cannot find the smallest clue throughout the whole of the Paper justifying any such results being arrived at; and then the last of the three perfectly distinct matters which are put before us is (and it is a very remarkable one, as the Meeting will observe), that if the conclusions under the second head could be obtained, namely, that you could obtain a vessel to go 14 knots and to carry an unheard-of quantity of guns, and an unknown thickness of armour—something like upwards of 4 feet

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is that which is named—one might have been content to have rested upon the acquirement of a vessel so totally superior to anything else that had ever been dreamt of. But then the third proposal ignores the second altogether, and goes on to urge that, with all the advantages that are to be got from circular ships, the right thing is to depart from and not produce circular ships, but to produce elongated ships. I really think that, in discussing this matter, as I hope and believe we all desire to discuss it in this Institution—first with regard to its truth, and next with regard to its being the foundation for future consideration in the development of this subject—we must look upon this matter in a less favourable way than that which the author of the Paper would have us deal with it. Now I propose to deal with a few of the subjects that are brought before us, in the order in which I have just now put them. First, with regard to the vessels that have been produced. It is rather a remarkable circumstance that the speed of these vessels has not been stated to us by the author of this Paper; but we have the means of gathering from that which he does tell us, that the speed of his *Novgorod* would in all probability have been 7 knots. The paragraph I refer to, which brings me to that conclusion is this, that "People forget when comparing "the speed of these vessels with the propelling power that was attained in English ships, that with "English engines they occasionally develope more than eight times the nominal horse-power, whilst with "the engines of the *Novgorod* they developed about four and a half times." Then it goes on to say that the *Novgorod's* speed, "had the engines been of the same efficiency as those English engines, would "have been 9 knots." Then, drawing as near a conclusion from that as I can, it comes to this, that if the 9 knots would have been obtained with eight times, the speed of $7\frac{1}{4}$ would have been obtained at the outside with that which was given. I believe, from what I have heard indirectly, that that was about the speed which was obtained. Now giving it the fullest advantage of that which we are able to derive from the statement put before us, what does it come to? It comes to this, that, if you enter upon the figures which are given to us in this Paper as to the resistance which this vessel has to overcome, and of the power which is given to it to overcome it, the mechanical power to overcome and cause this vessel to advance is five times as great as that which it would be in an ordinary ship.

Mr. E. J. Reed, C.B., F.R.S., M.P.: It is nearly that.

Mr. Samuda: I am very glad, indeed, to find that I am confirmed in that by Mr. Reed. Now what does that lead us to? It leads us to this, that if we have got that resistance with a vessel going at 7 knots an hour, and with a form that certainly is ill suited to go at great speed (and 7 knots an hour is probably the speed which would be the fairest and best that you could assume in comparing this vessel with others), what would be the result if you attempted to develope this to something like those useful speeds which have been treated in this Paper subsequently as perfectly easy of attainment? From the experience I have had in connection with steam—which has gone over as long a period, I think, almost as that of any one in this Meeting—my conclusion would be that no conceivable power that you could put in one of these vessels could drive it 14 knots. It could not be done. That is my conclusion. I think that it would be allowing the most complete hallucination to exist if one were not to attempt to elucidate some more correct conclusions from the facts which have been stated than those which are contained in this Paper, and if it were allowed to go forth to the world that there was read at this Institution a Paper which dealt with the possibility and certainty of acquiring these speeds when it is positively certain that it cannot be done. I have got now to the question of speed. This Paper puts before us, not only the statement that you can go 14 knots with these vessels, but that you can carry, when you are going at this speed with these vessels, "a similar very large coal supply as in the case of 12 knots' ships;" that

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" increased engine-power has taken more from the useful part of the displacement," but that she still possesses " the means of steaming 14 knots continually during five days and nights." Let me just call attention to what that would involve if you were to accept it as a problem capable of being carried out. If I take the *Kaiser* and the *Deutschland*—two iron-clad frigates I have lately built for the German Government, and which are two of the best ships of that peculiar form of construction for which Mr. Reed has had so much and such just praise, for here he carried to the greatest extent the beam of the ship as contradistinguished from the length of the ship—those vessels burnt, when going 14 knots, 10 tons an hour, or 240 tons a day; and therefore would have burnt in five days 1,200 tons of coals. I have already shown to you, and Mr. Reed has confirmed the view, that when going at 7 knots the quantity of coal—that is to say, the resistance of the circular ship in proportion to the engine-power—was nearly five times that of the ordinary ship.

Mr. REED: What ordinary ship?

Mr. SAMUDA: An ordinary sea-going vessel of the English Navy.

Mr. REED: Of what size?

Mr. SAMUDA: If Mr. Reed will let me give the details in my own way, I think he will find he will be answered more satisfactorily. Perhaps he may call his own ship an extraordinary ship, but I was going to compare the circular ship with the result of these very ships themselves—the *Kaiser* and *Deutschland*—and if they possess anything beyond the ordinary qualities, it will be all in favour of the vessel I am going to compare it with; because I am going to show what popoffkas would have to carry if their conditions were similar to those which we have already seen they actually do possess when going 7 knots. When going 7 knots they require five times the quantity of power beyond a ship of ordinary form; when going at 14 knots they certainly would require considerably more than five times the quantity of power. That is a natural conclusion, from the form of the vessel. If you only take them as requiring five times the power, you would require in this case 6,000 tons of coal to carry out the conclusion arrived at in this Paper. I put it to this Meeting whether it is right that we should have to discuss these matters which are purely imaginative to the extent which this Paper has evidently put before us? I am quite content to yield every kind of approval to the ingenuity of the plan where it is suitable; but the only place, to my mind, where these vessels could suitably be adopted would be in a position where a fort is required to be stationed, and is not required to be attached to the land. There they would be extremely useful. The power which is given to them, which is exceedingly minute as to their power of locomotion, might be very usefully applied to take them from one port to another. I am sure I need not offer any apology to this Meeting for putting this problem before them. The science of naval architecture is considered to advance in proportion as you are able to diminish resistance, and to make use of a given power to accelerate speed, and improve the passage of the vessel through the water. This power, far from accomplishing this result, does exactly the reverse—it involves the use of five times the power for a similar speed; and there is not a person of my age but can recollect that at the time when the first suggestion was made with regard to increasing the fineness of the lines of vessels, there was this remarkable result: all those vessels which had been built upon the river, and which were built with bows something approaching to these circular vessels—that is to say, with the full old sailing vessel bows—had those bows elongated, not very considerably so, but so as to make what was then considered fine lines. And with what result? This: that they immediately doubled the mechanical effect produced upon the ship. It is in that direction we have been working ever since, and

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we have gone on till we have produced something like good ships. Each alteration in that direction was considered an improvement of the ship, and this is doing away with the whole of that acquired experience. I venture to think that this Paper fails altogether to give us any insight into the mode by which any such conclusions as those contended for from the second problem here discussed could be obtained. I am willing to give the greatest possible credit to these vessels, so far as they have gone, when used simply as forts not requiring locomotion to enter into the condition of their floating powers, but I cannot extend my approval beyond.

Mr. WILLIAM FROUDE, M.A., F.R.S.: I wish to say a very few words on the subject. My friend Lieut. Goulaeff has referred to the experiments which I made by direction of the Lords of the Admiralty of the resistance of these ships, and perhaps I had better advert to the results so obtained before I attempt to discuss the general question. I must say, however, that I cannot feel so sanguine of extremely favourable results as he seems to be. I do not know where Mr. Samuda got his figure of 5 to-day, but it happens that about 5 to 1 expresses the relative resistances of the *Novgorod* or *Popoffka* and an *Inflexible* of the same displacement. There is another thing worth mentioning, which is to me rather a curious fact in relation to the resistance of these ships, namely, that up to the highest speed at which we drove them through the water their resistance was just as the square of the speed and not more—in fact it was rather less. So that you might infer from that that there would be some gain in pressing these ships to a high speed, because in other ships, generally speaking, as you approach high speed the resistances grow faster than the square of the speed.

Mr. J. SCOTT RUSSELL, F.R.S.: Not always.

Mr. FROUDE: In all that I have ever tried that is the case.

Mr. J. SCOTT RUSSELL: And in those I have tried it is the contrary.

Mr. FROUDE: That may rest for the present. With the *Inflexible* it appears that her resistance is pretty nearly as the square of the speed up to 14 knots—the highest speed taken account of—so that those two ships are capable of a tolerably easy comparison throughout. No doubt, as Mr. Samuda has said, the 5 to 1 resistance is a most formidable proportion to start with. Then I may say that the *Novgorod* of her natural size, 100 feet in round numbers—I think it is 101—will go up to 8 knots without encountering any of the formidable difficulties which she seems to encounter at the higher speeds. According to the correct scale of comparison, and indeed according to the old-fashioned mode of estimating—which is here equally applicable since the resistance is as the square of the speed is—the 320-foot ship would go 14 knots, making the same disturbance in the water as the *Novgorod* makes at 8 knots; but that ship, as I calculate it—I have only done it roughly—would come to 80,000 tons, and the reason why the 80,000-ton ship seems to do comparatively well is that, as we all know, as ships are enlarged their propulsive efficiency, that is their economy of propulsion, is greater and greater. The larger the ship the less power per ton is required to drive her at a given speed. I will not say I shudder, but I own that I am amazed, when I think of an 80,000-ton ship of that form driven through the water in that way. No doubt it would go if you put the power into it. I cannot say that I have calculated them carefully at all, but in the cases in which I have made some rough guesses, it seemed the weight of the hull and machinery and armour required by these round ships must be considerably greater in proportion than that required for an ordinary shaped ship if you went at the same ordinary speed. The substitution of a very small relative speed will tell somewhat in favour of the circular form; the result will not be so much against

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the circular ship and in favour of the other ship as at the high speed. I think the idea which has led to the adoption of the circular ship is rather a dogma than a practical truth. The view has been suggested that if you regard the thing to be sent to sea as a fortress—that if you wish to send thus a certain offensive power to sea, with some means of locomotion, and a certain means of carrying men and ammunition, and you wish to do that with the least weight, and the least cost, no doubt the circular ship seems to promise that the weight of armour, and indeed of the ship herself, will be less than for any other for a given form. Yet so far as I can see, if the proposition is fairly followed out, you will never rest at a circular ship, but you will be immediately driven to adopt some greater relative length in view of the necessity of greater speed, and the absolute length that you select must be decided by what you settle is the speed you wish to go at. I give great credit to Lieut. Goulaeff for the pains he has taken in working this question out, but I cannot believe that the ultimate result will be as favourable to the purely round ship as he has conceived it to be. Very much shorter ships for certain purposes may prove efficient, but I do not think we shall ever come to circular ships; we shall stop far short of that if we are guided by practical considerations.

Mr. NATHANIEL BARNABY, C.B.: I think that the first observation which I make in public on circular ships ought to be that I feel a great deal of admiration for the boldness of Admiral Popoff. I always admire boldness in anybody, and when one sees it in a man who is working in one's own profession, and who does something out of which you must learn a great deal, one's admiration is apt to become great, and mine is. I have great pleasure also in seeing that we have a description of Admiral Popoff's ship from a gentleman whose training was received in England, and I think the manner in which he has put it before the Institution does credit to his training. There are one or two points which are somewhat inaccurate in the Paper which I would like to remark upon:—One is a slight matter, but still it is an inaccuracy. He credits the *Inflexible* with 27 feet draught of water. I think that is some 2½ feet too much—I hope it is. In the Paper he has read to us, giving the dimensions and other particulars as to the *Novgorod*, Lieut. Goulaeff has not done himself justice, because he has not given the indicated power of the engines and the speed. Now he must know perfectly well that although he does not give them we know them, and it would have been better for him if they had been stated and not concealed, because it would appear that he wished to conceal them, which I presume he does not wish to do. He will probably tell us what his reason was for not giving the indicated power and the speed, which we have had to guess at. Mr. Samuda has guessed at it, and I daresay he is not very far wrong, and Mr. Froude has told us roughly and generally what it is interesting for us all to know with regard to the great question of the resistance which the ships have to meet in being propelled through the water; but as Mr. Reed has said many times, and which is quite true, that is not the only question we have to consider in a ship of war. I quite agree with that, but then I observe that Mr. Reed's view of this question is not the same as has been put before us this morning. We have been told that they were designed strictly for coast defence purposes, and for use in shallow waters. I am not the person to stand up and say they are not perfectly fitted for the purpose for which they were designed, because so far as I know they may be. But Lieut. Goulaeff goes beyond that, and treats them and puts them before us as ships capable of going to such a speed as ships should; and there, as he has already found, we are not able to follow him. Mr. Reed has very wisely called them points of departure, and I quite agree that as ships they are to be regarded only as points of departure. As coast defence batteries they may be as successful as you please, but as ships the sooner we depart from them the better. We have been told that it may be desirable to elongate them, and that after they are elongated the results which probably will be obtained from them may be great; and

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that we shall be able to call the vessels so elongated "popoffkas." I am sure for one I shall not have the least objection to calling them popoffkas; and if they should only have a small elongation of bow and stern they would turn out far better forms for propulsion, looking at all the advantages they get from their fulness, than the ships we are accustomed to use. But it must be borne in mind that we in England have been going down and down in the length of the ship. Mr. Reed came down considerably, and we have been going down since, shortening ships in proportion to their breadths; and everybody who knows Mr. Froude and Mr. Froude's labours, must know how hard he has been at work in proving for us what advantages are to be got by an increase in beam. I will before I sit down place on record one fact, which I owe to Mr. Froude's investigation—a point of considerable interest, in the matter of proportion affecting some little boats which we are now building. There were some gunboats designed for river defence, with 5 feet 10 inches draught of water, and it was a question what the proportions of those boats should be in order that they might go 9 knots. Mr. Froude was good enough to subject to experiment two forms, one of them having these proportions, 110 feet long and 26 feet broad, and he told us that for a displacement of 349 tons 330 horses would be required for 9 knots speed. But we had another form 110 feet long—that is the same length—and 34 feet broad; and he told us that if the displacement was 369—that is, 20 tons more—we should only require 220 horses instead of 330 to go at the same speed, the difference being due apparently partly to the proportions, and partly to the great fineness of entrance and run obtained by the increased breadth. The model of the boat to which I refer is lying on the table, and is the model of the boats which are now being built by Mr. Palmer for river service; and as I have spoken of them, it is right for me to say, that while I think the form an exceedingly good one—and I liked it before it was submitted to Mr. Froude for examination—the form is not due to me, but to one of the Foreign Members of this Institution, Mr. Carvalho, the Brazilian Constructor, who in fact had proposed to his own Government a boat of that form at the time we were considering it; and it was his form and our own we compared. I think that after what I have said you will see that we in England are ready to accept from any one, it does not matter to what country he belongs (for "science is of no country"), anything which seems to us to add to the efficiency of our Navy.

Mr. Reed: I think it will almost be expected of me to say a word or two on this question, looking to the fact that I am afraid I am partly responsible for the attention given to it. My friend, Mr. Samuda, has met with a well-merited answer, and I would almost say rebuke, in the facts just stated by Mr. Barnaby. For what do those facts amount to? Mr. Samuda having in the roundest manner condemned this plan, because it was for a very short vessel in proportion to its length, and upon the ground that all his experience, and everybody else's experience, goes to the point of greatly lengthening ships, if you want to get speed—almost immediately afterwards, a gentleman of official responsibility, and whose knowledge on the subject cannot be questioned, rises and tells us that in undertaking to build some vessels for the service of the Government—not armoured vessels at all—it was found by that most distinguished investigator, Mr. Froude, that if you increased the beam from 26 feet to 34 feet, with the same length, you reduced the horse-power requisite for propelling the vessel from 330 to 220.

Mr. Samuda: Would you allow me to rise to explain? Mr. Reed is quite in error in imagining that that is a rebuke, because it is an entire confirmation of my own statement, for Mr. Barnaby stated that the great reduction in the horse-power with the greater beam arose from the fact that you were able to give finer lines from carrying practically the same displacement in a wider vessel with finer ends.

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Mr. REED: Well, my Lord, if that is a satisfactory answer to the state of things, then I think we may certainly find in it a corroboration of this view, that the circular ship has only to have given to it very fine lines at the bow and stern, in order to become quite right. If that be so, it is the most ample confirmation of the one view which I have always held about these vessels, and that view is this: I have never stated, although it has often been imputed to me, that I thought the circular form was the most desirable form for a fast ship. The furthest statement in that direction that I ever used has been that I did not believe it impossible, as my friend, Mr. Samuda, does, but I believed it possible to drive them fast; and on that point I must say I think in this scientific Institution that when Lieut. Goulaeff has placed before us to-day a scientific investigation of the grounds of his belief in its being possible to drive them at a high speed, it is much to be regretted that no one should in the least degree have touched his scientific argument and investigation, and that no allusion has been made to his diagram up to this moment, but that he should be condemned by *à priori* references, and on that oft-abused ground of "authority" which was invoked. Nothing as yet has been said, and it remains to be seen whether anything will be said, in disproof of the grounds on which Lieut. Goulaeff has proceeded in his Paper with reference to that diagram. For myself, I may say that I have not given that diagram sufficient consideration to be able to express any opinion upon it, and I do not claim for my original remark anything more than that, seeing the extraordinary and unexpected behaviour and steaming power of the *Novgorod*, in which I travelled many hundreds of miles in the Black Sea, I did, I confess, express the opinion given without minute inquiry, that, if it were necessary or desirable, you might drive a circular ship very fast. My view is that there was not a single reference in the speech of my friend, Mr. Samuda, that touched at all the merits or demerits of this form; and for this simple reason, that to my mind it is the idlest thing in the world to talk about resistance, in total disregard of the thing you have to carry about. What you have to carry about in an armour-plated ship is armour and guns; and you, my Lord, took a lively interest in the *Warrior*, and my friend, Mr. Scott Russell, also took an active part, no doubt, in her design, and all of us have been for years proud of the *Warrior;* but I believe there is not a single soul in this Institution at the present moment who would say that, in order to send guns and armour to sea you would dispose of them after the fashion of the *Warrior*, because there you employ no less than 5,400 indicated horse-power to send 4½-inch armour about the seas to cover very light guns. This question must be considered from that point of view, if it is to be considered with any scientific result; and I should like to ask those gentlemen who spoke so strongly against this class of vessel, if they will be good enough to refer me and this Institution to any vessel whatever in the whole world, except the *Novgorod*, which carries at from 7 to 8 knots armour 11 inches thick, and two 28-ton guns. There is no other vessel in the world that does it.

Mr. BARNABY: Nine inches.

Mr. REED: Mr. Barnaby says 9 inches. The explanation of that is simply this, that the Russian authorities have introduced a heavy backing in the form of channel rails, which takes the same place as armour, and which it seems to me most desirable should be reckoned if we are to consider the weight of armour which is carried about. What I think is this—we started, when we began armour-clads, with the *Warrior*, and I say that the *Warrior* is already out of consideration as an armour-plated construction. The Russian Government have begun their efforts, at least with regard to this class of vessel, with the adoption of an exceedingly short vessel, no doubt, and we have heard to-day of vessels building by the

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Government which are slightly over three times their beam, without any armour at all. Now the inference that I draw from all that is this, that if we, as Mr. Barnaby candidly and fairly put it, take the circular form as a point of departure, and put to it such bows and such sterns as we can afford to put, with gain in the point of economy of fuel all the time we are extending them, and without incurring other and serious disadvantages as regards the sacrifice of fighting qualities, then I say that we are bound by every scientific consideration to depart from the circular form to that extent, whatever the speed may be that we have to aim at. But if, on the other hand, it be true that with an unarmoured vessel you can come down to three beams to the length of her with advantage, surely that is a striking suggestion at any rate that in heavy armour-clad vessels it may be desirable to put but very short bows and sterns upon them; and I showed in a Paper which I read elsewhere a little time ago, that by putting very short elongations at the bow and stern you can probably get rid of a very large part of those causes of resistance, which, as Mr. Froude so well knows, attend this circular form of vessel, and is the occasion of that four or five times the ordinary power which is required. I wish to be clearly understood in the matter. I am not able to affirm all the investigations of my friend Lieut. Goualeff: that is because I have not studied them sufficiently to do so; but they have not been contravened, and they will certainly form a worthy subject of consideration to Members of this Institution. But I do believe myself that very short iron-clads will become the order of the day, and that the inducement to make them so will increase more and more as the thickness of armour is increased also. After the debates of to-day I think we may feel that one thing is quite certain, and particularly after the speech of Mr. Barnaby, which he has just delivered, and that is, that however anomalous, and unusual, and extraordinary this circular form of vessel may seem, it will be considered with thorough impartiality, and with that propriety of view which it ought to receive in this country. I must say also for Admiral Popoff, and for his friends in Russia, that they are most anxious, as Mr. Barnaby knows, to have all the results of experiments published as soon as possible, so as to get the question brought within the view of scientific investigation. I will conclude by saying that having made several passages in this *Novgorod* over the Black Sea, one of them in eminently rough weather, I was gratified to find that I made those passages with the greatest possible comfort; and that when the sea was rolling freely over the deck of the vessel, and when the waves were running to considerable height, indeed so high that you could not stand on an elevated bridge at a very great height above the water because of the lash of the sea, you sat in the cabin in the deck-house with the ship in a state of almost absolute tranquillity—no rolling worth mentioning to trouble you, and scarcely any pitching. It is due to Mr. Froude to say that he was the original suggestor of the defect which I believe is the strongest of all reasons for not hastily adopting the circular form in the fast vessels. And he has shown that you may easily, when the ship is steaming fast in this form, establish a synchronism, as it were, between the period of the ship and the period of the wave, and that would result in great plunging. I am sorry to have trespassed upon the Institution, but I thought it hardly proper that I should not make these remarks. I do hope that, from this Institution at any rate, while we shall have listened I trust with interest and benefit to the Paper of Lieut. Goulaeff, and while we study it afterwards in the same way, it will not go further that I am a maintainer of the circular form under all conditions, and without any modification. I believe that for speed it must be modified, but that the modifications will be very much more limited than some friends of mine seem disposed to think. My Lord, perhaps I may relieve your mind and mine by saying that I think my Paper, which comes last, might very well be withdrawn. It is simply a Paper for record in the *Transactions*, and is not intended to invoke any discussion at all.

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The PRESIDENT: I must, of course, be in the hands of the Meeting. We have come to the difficulty which I feared this morning, and I am afraid it is absolutely impossible, having regard to the fact of an Evening Meeting, to finish the Papers put down for to-day. I understand Mr. Reed to say that he will not press the Paper in his name; but there is a Paper on the subject of "Cellular Ships"—an interesting question at all times, and especially so at this present moment; and unless this Discussion on Lieut. Goulaeff's Paper is to close, I am afraid we must give up "Cellular Ships," and that will be a very great loss. Therefore I must leave it to the Meeting to say what course they would like to take. Mr. Scott Russell naturally wishes to speak on Lieut. Goulaeff's Paper, and I should be most happy, as I am sure everyone here would be, to hear him; but, if we are to continue this Discussion, it must be on the understanding that Mr. Boold's Paper is to be given up.

Mr. J. SCOTT RUSSELL: My friends around me say I had better go on.

The PRESIDENT: If that is the opinion of the Meeting, I have no objection.

Mr. J. SCOTT RUSSELL: Allow me to say that my strong wish to go on is to do justice to Admiral Popoff's circular ship; and I think I shall do the greatest justice to his circular ship if I try to direct our minds to what its real advantages are, and if I try also to divert the minds of my friends away from what I think the fictitious advantages which have been asserted for it. I believe that Admiral Popoff's invention is, for some purposes for which he made it, an extremely admirable application of the circular form. I believe, on the contrary, that whenever you claim for that the advantages which it has not, you do great harm to Admiral Popoff and injustice to the inventor. Permit me then to say what I think, most unquestionably, is the great advantage of the circular form as here applied to ships of war. It is simply this, with a given quantity of material the circular form will give the greatest cubic contents. With the circular form you will carry, with a given quantity of ship material, the greatest quantity of dead weight; and with the circular form, and its large dimensions equally all round, you will do the most a ship can do to obtain a steady platform with equal command all round. If, therefore, you will, with this form, carry the greatest amount and greatest thickness of armour, and carry the most powerful of armaments, have I not said enough to recommend this to your careful attention? And now I go to the second point. The second point is this:—When you have got circular floating fortresses, with the greatest possible amount of armour, and the greatest possible amount of armament, then comes the question, Is it desirable to move these floating fortresses from one place to another? The answer to that is, that there are many cases in which they ought not to be moved, and ought not to have facilities for moving; and there may be other most important cases in which it is desirable to move them. Then comes the question, Will you remove them by towing them by other vessels around them, or will you furnish these floating batteries with engines and engine-power and fuel to move themselves? There the question becomes a critical one—there it becomes a question that is answerable in a different way, according to different circumstances. Allow me to tell you, that, having served on a Defence Commission, I know there are many cases in which it was desired that such batteries should not have the power within themselves of moving themselves. I now come to the next point. The vessels having great qualities as floating batteries, and having great qualities also which enable them to be moved from place to place, I consider that, in the circumstances for which Admiral Popoff built these vessels, they were very wise vessels; and I do not think that economy of mechanical power, or their fitness for long voyages, or their

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being very seaworthy ships, had anything material to do with the purpose for which Admiral Popoff immediately designed them. Therefore to him and to the Grand Duke Constantine, the head of the Admiralty, I think belongs great credit for having first had the courage to introduce so economical and so powerful a machine into the naval service; and I know several situations in England in which a circular battery of enormous power, on this principle, would be a fortress of very great value. I know such places. And now, leaving that, I go to the next point. In regard to the construction of ships meant for a given speed—meant to carry given weights—meant to accomplish given purposes—meant, for example, for given lengths of voyage, Does the circular form give us any information we did not possess before? Does it give us the power of making a ship in any way better or different from what we have already been in the habit of doing? I answer, none whatever. I answer, no new information of any kind is obtained; no additional knowledge is communicated to us of any kind. This circular form has none of the advantages that we want for a sea-going ship, and everything that it can tell us we have long known. I wish that it should go forth from this Meeting, and be thoroughly understood, that we shipbuilders and engineers, who know our business, do not build ships out of our own heads, and do not build them of our own whims; but we do build them for distinct, clear, specific purposes, and we allow the purposes to create the ship. Allow me, then, to show you why I should at once deviate from the circle, if I had got, not a floating battery to build, but a ship or a ship of war. If I had to build a ship or a ship of war, and you told me that this circular form was the form in which—although it would carry all you wanted—you wanted me to make a ship, which should have the same beam, but go faster, What should I, at once, have to do? You know what I should have to do; you know that I would lengthen the circle that way [*describing*]; and I know exactly how much to lengthen it if I want a given speed. Tell me the speed, and then the quantity I have to lengthen it is all contained in printed Tables. Having lengthened this line, mathematically, both ways, say to each an additional diameter, what do I do next? I take the well-known curve of sines, on which all we shipbuilders make the lines of our fast ships, and I take simply the ordinary mathematical form of the curve of sines in the water-line—I am not drawing the ship out of the water, I am drawing the water-line of the ship—and I do that at both ends; and what have I got? Do you mean to call this, now, a circular ship? This is the old-fashioned boat, three beams to her length; and when I was a young man, and was first sent to sea, those were the lines of the fishing boats of the North Sea, in which I first learnt what a sea was made of, and what waves meant, and how boats behaved themselves, and how waves behaved themselves to boats. I have now changed the form and transformed your circle, and what have I made it? I have made it a modern wave-line ship. And what have I done? I have done the very thing Mr. Reed was praising in these boats. Mr. Reed was delighted to see that a boat, with a very broad beam and very short ends, could be made to go wonderfully quicker and with wonderfully less resistance than a boat with much less beam and fuller ends. Of course it could. That was the discovery we made in the present century, that, by sharpening the ends of a ship, and by making her very much wider, the sharp ends would go a great deal more to diminish her resistance than the beam did to increase it. I remember one of the first of those new classes of ships was built under the following circumstances. This new form was made to beat the old form by a new man coming and building a boat with 6 feet more beam than the old boat with the same length as the old boat, and with engines two-thirds of the engines of the old boat, and the new boat beat the old one. There is nothing, therefore, in this matter that we do not already know. What is the next step? The next step is this: If you tell me that you want this

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boat to go so much faster, I then add another beam, and another beam, and then I continue *this* line in this manner, and *this* line in this manner, and *this* line in this manner, and *this* line in this manner [*describing*], and what have I now done? These are the curves of sines, and what are the sines? The sines are only, after all, ordinates of a circle. What have I done? I have merely manipulated the circle. I have taken the circle; I have introduced no new element, I have taken the sines of the circle—its own progeny—and I have merely put these sines of the circle in the right place, and they have brought out the right shape of ship, and I am sure you will agree with me that that is the right shape of ship, and this other is the tub shape of ship. Allow me to say that there is no whim, fancy, or caprice in anything I have laid down there. These are the mathematical inevitable lines of a ship. And now I have only to say that when the ship's speed is given, this length is given without leaving us any choice. This is a minimum length; and if we do not take that we know that we waste power, or do not get the speed we ought. What is the next thing to do? The next thing to do to this ship is this. At present this ship that I have shown you will go at the speed you want, but she will not go a long voyage at that speed. What is the reason of that? She will not go a long voyage at that speed, because for that amount of beam she must have a given horse-power; and for that speed she must expend her fuel and her horse-power at a given rate, and therefore this vessel is not a vessel that can remain at sea—she cannot keep the sea long enough; and, therefore, though I am a great advocate, as I have told you, of very broad ships with sharp ends, though I am a great advocate—and every man who has owned ships must be an advocate—for making a ship not a foot longer than she requires to be made, and must be made for her speed, yet if I want this ship now to be a ship able to keep the sea, and if I want her to go a certain length of voyage and back again without coaling, which as a good ship doing our ocean service, or our sea service, she must do, I have no choice but to lengthen the ship. Perhaps Mr. Reed will tell me that I have the choice of making the ship broader. Yes, I have. But as I have already given her that breadth, and as I have already given these fine lines at the ends, as before I say I have no choice. What have I to do now? I will tell you what I have to do. I have to stick in the middle of this ship, what? I will tell you. For every fifty miles I want that ship to steam I have to stick on an additional foot of length of body, whether I like it or not. If, therefore, I want this ship to steam 1,000 miles, I have to put (I will not calculate it exactly just now) about 25 feet into her length, and then this portion I have added will carry fuel enough to take her 1,000 miles. But suppose you tell me I must have fuel to take her 2,000 miles, I have no choice. I go back again, and put 25 feet more into the middle of her, so that she may go another 1,000 miles, and if you take 3,000 miles, I have to repeat the process each time; so observe that I do not make the ship, you make the ship—the work she has to do makes the ship—the conditions make the ship. But you say, Could not I do all this by merely increasing the beam? I answer Mr. Reed, No. I think myself a clever fellow, and I tell you, "No." When I have already fined the ship as much as she ought to be, and when I have already given her the right length proportioned to her speed, I tell you I cannot make her go a longer voyage upon that given length—I have no choice. Widening her will not do; filling her up will not do; nothing will do except lengthening the body of the ship. I have now shown to you, I hope, that when you talk of making short ships do the work of long ones, it is out of the question; that when you talk of making a ship do a given speed and a given length of voyage, the length of your ship is found for you, and when you say you will make a circular ship of this kind do anything of this nature, I answer, "Yes you can," and you can make her do it by making her shape to be a circular shape, and by making her a ship with the water lines which

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transform the circle out of what we call the shape of a tub, into what we have always called a ship-shaped vessel.

Sir R. Spencer Robinson, K.C.B., F.R.S., Admiral: I do not rise to prolong this Discussion, as I consider that it cannot be terminated without a great deal more explanation than has yet been given to it, but I wish to ask whether it is not possible that some arrangement may be made by which many gentlemen who wish for further information upon the facts with regard to this circular ship should be enabled to obtain them, and to bring their understanding and comprehension to bear upon what I think the not only very difficult problem, but the most interesting problem that is set before us. Unfortunately the worthy gentleman who read the Paper to us is not so conversant with the English language as I wish he had been; and it was to me, and I have no doubt to many gentlemen here, a very great source of loss and difficulty that we could not follow him in his demonstrations. When Mr. Froude—than whom a more scientific analyst of all the questions that affect naval architecture there is not—rose, I did anticipate that he would have enabled us to understand these diagrams which are before us by a brief explanation, because there is no man more capable of showing in a few words what is meant by those figures than Mr. Froude, and I had hoped he would have told us a little of the exact effect of those lines, and of the effect of multiplying resistance or deepening vessels in the water; and of the various reasons, experimental and scientific, which prove, or do not prove, the utter impossibility of such a ship ever being converted to the ordinary purposes of a ship. I confess I was very much struck with the decided condemnation that my friend Mr. Samuda gave of so interesting a design, and I listened with the attention that every word which falls from him rightly commands, to hear the grounds on which that condemnation was so unreservedly pronounced. I was not fortunate enough to follow Mr. Samuda, or to be convinced by him, neither have I been convinced by the able speech of Mr. Scott Russell. There is no doubt that whenever Mr. Scott Russell takes the trouble to tell us anything, he tells it in such charming language that I almost feel myself in the position of Eve and the old serpent. I cannot find it in myself to resist those eloquent periods, that magnificent declamation, and those very sound and sensible points which Mr. Scott Russell puts before me—although sometimes I cannot help thinking it is my imagination, and not my reason, which gives way to his arguments. What I really wish to say is this, that no subject of more importance I will venture to say has often been brought before this Institution than the subject of these circular ships. What I contend for, without having any fixed opinion upon the subject as a naval officer deeply interested in the right construction of our ships, and in the due adaptation of them to the work they have to perform, is that we should have some more scientific and complete exposition of all the points which constitute this circular ship, as shown in those diagrams, as derived from Mr. Froude's experiments, and that if possible by some adjournment, or by some other arrangement which I am not called upon to suggest, we should have some further explanation if Mr. Froude will give it.

Mr. Froude: I shall be very happy to do so.

Sir R. Spencer Robinson: If Mr. Reed, who has not as he has told us to-day thoroughly investigated this matter, and Mr. Froude, and the talented author of this Paper, would specify the points to which more attention should be given, and give us more explanation and information upon them, I think that this Institution would stand in a better position than that in which it now stands after the very unreserved but apparently very unsatisfactory condemnation of something so great, so novel, and so powerful as the circular ship that we have just had described. I think it would not be to the credit of this Institution to

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pass the thing over *per saltum*, and with a great deal of laughter and fun, simply to laugh the thing out of Court. The matter is too important and serious to be dealt with in that way, and I think if possible more time should be devoted to the subject.

The PRESIDENT: I must say that I most entirely agree with what has fallen from Sir Spencer Robinson, that it is most desirable so important and so novel a question as this should be fully discussed; and I hope no one will suppose from what has fallen from me that I desired to shorten this Discussion. I am sure everybody will allow that in this chair my duty is simply to carry out our Regulations. I agree with Sir Spencer Robinson entirely. I think it is almost due to Lieut. Goulaeff, who has given us a Paper of great ability, and has contended very successfully with the difficulties that every foreigner has in dealing with a great subject in a foreign language. I think also we are very much indebted to him for having read that English Paper with a rapidity that very few Englishmen could have done—at all events it had that merit, and his Paper is entitled to full discussion. I do not know what to suggest, as the time is now twenty minutes past four. If Mr. Boolds is disposed to withdraw his Paper, which it would be very difficult now to do justice to, we might sit and continue this Discussion until five. I do not see how we can sit after five, with due regard to the Evening Sitting. Another suggestion I might offer would be to renew this Discussion at eleven o'clock instead of twelve to-morrow morning, so as to have an hour before the regular Papers of the day began, but still I very much doubt whether that will be sufficient. I am the more disposed to throw out the suggestion whether the difficulty we are now in does not bear very closely on the suggestion that I threw out for consideration this morning, whether this subject is not of so much importance as to be well worthy of a distinct sitting of this Institution. I think on the whole that is the most practical suggestion that I can offer; and, as that seems to find favour with the gentlemen who are now here, I will venture to suggest that we should now pass to Mr. Boold's Paper, and that at the Council Meeting, which is always held at the end of these Annual Sessions, the Council shall take into consideration what is the most practical and best mode of reviving this question at some subsequent period.

Mr. THOMAS BRASSEY, M.P.: If it were possible for the Council to take into consideration the propriety of a sitting on Monday morning, with the view of completing the Discussion, I should be very glad.

Mr. J. SCOTT RUSSELL: On Saturday evening.

The PRESIDENT: We had better not begin now the discussion we shall have in the Council. I think the practical point is whether we shall in the Council consider it wise to revive this Discussion. I think that suggestion seems to find favour with the gentlemen here. I cannot even now close this present Discussion without expressing my acknowledgment to Lieut. Goulaeff for his able Paper, and for the clear mode in which he read it to us considering his disadvantages.

On Saturday, the 8th April, the Morning Meeting was presided over by the President, Lord HAMPTON, who commenced the proceedings by saying:—The time has now come for commencing our proceedings, but before I call on the author of the first Paper, I wish to mention that this morning, at a meeting of the Council, the question has been considered which was raised on Thursday last, whether under all the

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circumstances it is desirable to appoint another day with a view to a renewed Discussion of Lieut. Goulaeff's Paper with regard to Circular Iron-clads, and on the whole the Council are of opinion, although we feel much regret that the circumstances in which we were placed prevented the continuation of the Discussion on that day, that appointing another day for a revived Discussion is a very different question. Some gentleman the other day suggested that we might revive it on Monday next, but I am sorry to say it is found upon consideration that from want of notice and other reasons that would be impossible. On the whole, although much regretting the necessity of coming to that decision, we are of opinion that for the present, at least, it would be very difficult, if not impossible, to revive that Discussion. But I cannot make this announcement without repeating to some extent what I said on the first day of this Session, that it is a serious question whether or not the present Rules and Regulations under which we act, do not tend upon some occasions (and this would be a remarkable instance of it) to curtail our Discussions of these Papers to an extent that is disadvantageous to the public interest. Of course, I, sitting here as Chairman, have no option excepting to the extent to which I am supported by the Meeting. All I can do is to carry out our Regulations; and, above all, to carry out those Regulations so far as I possibly can with the strictest fairness to all those gentlemen to whom we are so greatly indebted for devoting their talents and time to the preparation of the Papers, and also for coming here to read those Papers which lead to discussion. That is a practice we must not abandon; and it must, of course, be carried out with fairness and strictest regard to the claims of the gentlemen who give us that valuable assistance; but it is deeply to be regretted that under the existing Rules it does operate sometimes in a manner that we must all regret, and as I have said, I think this is one of those cases. Therefore, I announce that as the decision at which the Council have arrived.

Mr. JAMIESON (of John Elder & Co.): My Lord, I regret very much this decision of the Council. I came to hear the Paper by Lieut. Goulaeff, "On Circular Iron-clads," read, and state my views respecting it; but, as the decision of the Council has limited the Discussion to the gentlemen who have already spoken, I trust that I may be permitted to make a short statement respecting the claim of the late Mr. John Elder, of Glasgow, to be the inventor of the circular iron-clad ships of war which Admiral Popoff assumes to be, through Lieut. Goulaeff, in the Paper just read at this Institution. The facts of the matter are pretty much these:—For a number of years Mr. Elder's private friends were aware that he was engaged in considering the subject of circular iron-clads, previous to giving his views to the public in September 1867, and reading his Paper, at the United Service Institution, in May, 1868, and that he discussed them with the officers of various Governments—Admiral Popoff included—and Mr. Elder thought the chief object of Admiral Popoff's visit to Glasgow, in 1868, was to get full information regarding the details of his circular ship, respecting which Admiral Popoff was quite enthusiastic. Mr. Elder became unwell in the winter of 1868-9, and, but for his death in September, 1869, would, no doubt, have carried out his intention to build an experimental vessel, at his own expense, to cost about £10,000. Lieut. Goulaeff now says it was in the beginning of 1869 that Admiral Popoff conceived the idea of his circular ships, *i.e.*, after Mr. Elder had published his specification and account of them more than a year, and two years after his first interview with Admiral Popoff. In his Paper, just read to this Institution, Lieut. Goulaeff describes the curvature of the bilge as being the arc of a circle, and the bottom flat, whereas, in his original description, he describes the bilge as ascending in the quadrant of a circle from the bottom to the deck. Mr. Elder's description of his vessel—made eight years before—was, if for light draught, the bottom would be flat, with the side rising or radiating to the

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deck; and, if for high speeds, the form of the bottom would be spherical. It is, therefore, apparent Mr. Elder's plans are being adopted, the terms employed in describing them only being somewhat varied. It is on these grounds, as a personal friend of Mr. Elder's of long standing, and as due to the memory of a great man, I protest against his being robbed of the fame of the invention of circular iron-clads, which involved so much of novelty in conception and construction; a task for which his other inventions and improvements—particularly the compound engine, which has conferred such immense advantages on the country and the world—proved him to be eminently capable; and I do trust these remarks will be put on the records of this Institution, as giving an account of the origin of the circular type for vessels of war being the conception of Mr. Elder.

The PRESIDENT: I merely wish to say, that I think Mr. Jamieson has expressed himself in a most moderate and considerate tone; and for myself, and I am sure that when I speak for myself I speak for the whole of this Meeting, I do very deeply regret that the want of time on Thursday last deprived Mr. Jamieson or any other gentleman—I believe there were other gentlemen—of the opportunity of making any statement they desired to make. Under the circumstances, as it comes so near the nature of an explanation, I apprehend the reporters have taken down the explanation offered by Mr. Jamieson; and I certainly, for one, should offer no objection to that explanation appearing in our *Transactions;* but I would also add this:—Mr. Jamieson must be perfectly aware that the press is open to him to make any explanation he may think it right, for the reasons he has mentioned, to set before the public.

Mr. NATHANIEL BARNABY: Perhaps I may also be allowed to offer one word of explanation with regard to a matter to which I gave Mr. Reed notice that if there was an opportunity I should refer. It is to a statement which Lieut. Goulaeff made in his Paper. He spoke of the *Inflexible* as the embodiment of Mr. Reed's favourite design of a citadel ship. This is likely to leave on record in our *Transactions* a statement open to some misapprehension. The *Inflexible* does not embody any design of Mr. Reed's any more than other ships now building—the *Nelson* and *Northampton*, for example, which are cruising broadside ships, with only a belt of armour—can be said to do. Mr. Reed does not himself, as I understand him, claim more than the idea of omitting vertical armour from the ends of ships, and substituting horizontal armour for it.

The PRESIDENT: I hope that there will be no misunderstanding or misconception with regard to the course taken to-day. I think it quite right that Mr. Barnaby should have had the opportunity of making this explanation; and I think it right that Mr. Jamieson should also have had the opportunity of making the explanation which has fallen from him; but I trust the Meeting will understand, and I feel it to be my duty not to object to the course so taken by those two gentlemen, on the ground that it was clearly understood on Thursday last that the Discussion on Lieut. Goulaeff's Paper was not concluded—it was still an unfinished Discussion, and therefore explanations may now be fairly admitted.

Lieut. E. E. GOULAEFF, F.R.S.N.A.: I should like to offer some explanation in reply to what Mr. Jamieson has said on a subject which has not been brought up by my Paper, and which only to-day he has brought under your notice.

Mr. J. SCOTT RUSSELL, F.R.S.: I rise to order. I ask Lieut. Goulaeff just to make the motion he was going to make, that the additional information he has got, and the additional calculations he

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has made, should be laid on the table and placed at the disposal of the Council for the purpose of being printed. Would you move, Lieut. Goulaeff, that your Paper and calculations be laid on the table?

The PRESIDENT: We should all wish to do the fullest justice, Lieut. Goulaeff, to the part which you have taken so ably in these Discussions.

Mr. J. SCOTT RUSSELL: I am afraid I must also ask your permission to lay on the table three documents which have been sent to me, which are of great importance to this subject. I have been sent documents containing, first, an accurate drawing of the circular merchant vessels at present in use in Asia Minor, and on the Euphrates, taken from a photograph; second, the description of round ships as given by Herodotus; thirdly, a photograph of round merchant vessels as now in use in Eastern waters. These documents I beg to lay on the table.

The PRESIDENT: I had no idea this Institution, valuable as it is, was likely to become an institution for the promotion of classical literature.

APPENDIX.

The following is the Paper laid on the table by Lieut. GOULAEFF:—

Since the Discussion which followed the reading of my Paper on Thursday, I have certainly had no direct reference to the subject which I have brought under your notice in the Paper—at least in the second part of it; I should therefore consider it as a great favour if you, my Lord and Gentlemen, will allow me to submit to you the following short description of the diagram, by means of which *I proved* the capability of circular ships of moderate length and draught for carrying enormous guns and armour with a speed of 12 and 14 knots.

The questions before us are:—(1.) Whether the circular ships, when made sufficiently large, *have or have not* the displacement to afford them the power to carry engines necessary to drive them through water at 12 or 14 knots. (2.) Whether carrying such engines, the circular ships *can or cannot* carry guns and armour, and whether the capacity of lifting these guns and armour increases or decreases as the ships grow bigger.

To answer these questions I will take the largest ship which I have considered. She is 320 feet in diameter, 27·4 feet draught, and has a displacement of 53,920 tons. In reply to the first question: The bases of my calculations of indicated horse-power, as was explained in the Paper, were certain *definite* results obtained by Mr. Froude, relating to the resistance of a model of a circular ship 160 feet in diameter and 13·7 feet draught.

If, having certain definite results derived from the experiments with the model, you accept these results, and infer from them the resistance of an actual ship, say 100 times the dimensions of the model, the same faith must be given to the application of the results derived from a model for ascertaining the resistance of a ship 200 times the dimensions of the model.

I trusted that Mr. Froude's valuable contribution to science—his "law of comparison"—was generally known, but from the Discussion it appeared to me that such was not the case, or else the possibility of moving large circular

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ships at great speed would not have been denied. Therefore, I will state it briefly: If the bigger ship be D times the dimensions of the smaller ship and if at the speed V the ascertained resistance of the smaller ship is R, then for the speed $\sqrt{D}\,V$ of the bigger ship, the resistance will be $D^3 R$. Therefore in order to obtain the indicated horse-power necessary to drive at 14 knots the 320-feet circular vessel, 27·4 feet draught (which is the 160-feet vessel 13·7 feet draught, increased *twice*) it would be necessary to find the speed of the 160-feet ship which corresponds with 14 knots for the 320-feet ship; to take the resistance of the 160-feet ship at that speed, and to multiply it by the cubed ratio of the dimensions, namely 8.

Calling V the speed of 160 feet, corresponding to the 14-knot speed of the larger ship we obtain—

$$\sqrt{2} : \sqrt{1} :: 14 : V\text{; or, } V = \frac{14}{\sqrt{2}} = 9{\cdot}9.$$

Resistance of 160-feet vessel at that speed is 355 tons.

∴ Resistance of 320-feet ship at 14 knots will be $= 35{\cdot}5 \times 8 = 284$ tons.

According to Mr. Froude's formula—

$$\text{I.H.P.} = 2{\cdot}3 \times 284 + \tfrac{1}{6}\,2{\cdot}3.\ 284 \text{ at } 14 \text{ knots} = 73{,}404.$$

So far the calculations were checked by Mr. Purvis, of Mr. Froude's professional staff, and he wrote to me, "On "account of arithmetical difference between your work and mine, I should bring the indicated horse-power figures "out about 1 per cent. lower than you do, which I think we needn't squabble over."

The weight of engines, boilers and water in the *Devastation*, the last of the twin-engine ships, amounts to 1,000 tons. The indicated horse-power developed was 6,600, therefore each ton of engines developed 6·6 horse-power.

I might have submitted to you the names of the new actual ships having a smaller proportion of weight of engines in proportion to the horse-power developed, but I can be liberal in dealing with circular ships.

According to the *Devastation* data—weight of engines $= \frac{73{,}404}{6{\cdot}6} = 11{,}211$ tons. Such weight would be necessary to drive the ship under consideration at 14 knots.

I have taken the coal consumption per indicated horse-power per hour as $2\frac{1}{4}$ pounds. I might have submitted the names of certain ships provided with compound engines in which the coal consumption is less. However, using the figure $2\frac{1}{4}$, we shall have $\frac{73{,}404 \times 2\frac{1}{4} \times 24}{2{,}240}\ 5 = 8{,}845$ tons of coal supply necessary to keep the ship steaming during five days continually at 14 knots.

It would be evident to everybody that as the weight of engines + the weight of coal, corresponding to 14 knots for five days is equal to 19,966 tons, and as the displacement of such a vessel is 53,920, therefore such a vessel *is able* to float the machinery necessary to drive her at 14 knots.

That answers my first question.

In reply to the second question—Assuming that in such a ship the crew, provisions, stores, &c., amount to 800 tons, no less than 33,920 is left for hull, armour and guns.

Weight of Hull.—The weight of the *Novgorod's* hull, including half of the skin and the deck plating beneath the deck armour, is 22 per cent. of the displacement. Adopting the same per centage in a 320-feet vessel we shall have the weight of hull equal in that ship to 11,862 tons.

I may here mention that the *Transactions* for the year 1874 contain a record of an attempt to generalize the question of the useful displacement as limited by the weight of structure and propulsive power. In this Paper, read by Mr. Froude, he says (page 150):—"From this follows the remarkable result that alike whether we enlarge

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" a ship by increasing her three dimensions throughout in the same given ratio, so as to enlarge her total displacement " in the cube of that ratio, or whether we enlarge her by increasing her length alone, the ratio, in which the " structural weight should be increased is the fourth power of the ratio in which the dimension is enlarged." When asked by Mr. Merrifield, " whether his theoretical notion of elongation meant the same kind of proportionate " elongation which takes place when we convert a circle into an ellipse ?" Mr. Froude answered, " I meant the last."

Therefore, from this we may infer that part of the hull which is meant to resist the general strains would be the same whether we elongate a circular ship 160 feet in diameter and 27·4 feet deep, twice only in direction of her length, or enlarge it twice in all directions so as to obtain a circular ship 320 feet in diameter and 54·8 feet deep. If the larger ship of these two would have the weight of hull of 4,000 tons (approximately true), the weight of hull which I have adopted in my calculation for a circular ship, namely 11,862, is certainly sufficient, if it is not too great to resist local and general strains.

Again, it is evident that if each linear foot of a circumference of a circle corresponds to 80 square feet of the area enclosed, each linear foot of a total perimeter of four long water lines inserted in this circle corresponds only to 25 square feet (co-efficient of fineness supposed to be 0·7) of the total area enclosed. The ratio $\frac{80}{25}$ being = 3·2; also gives a certain indication of the proportion in which the surface of the circular ship is less as compared with that of four long ships, having their *length* equal to the diameter.

The weight left for armour and guns, out of the whole displacement will be 21,292 tons. The system of mounting guns was explained in the Paper, the armour was supposed to be arranged according to one of the systems described in Mr. Reed's United Service Institution Paper. Thus, the weight of 21,292 tons I have distributed in the following way :—

Vertical armour, 4 feet 6 inches thick, protecting guns, with backing and ($\frac{1}{2}$) skin	11,888
Horizontal armour, 2 inches thick, protecting the outer circle of thin iron and laid over the $\frac{3}{4}$-inch deck plating	1,112
Thirty 80-ton guns, their carriages, shot and shell	8,160
	21,160
Spare weight ...	132 tons.

Thus, so far as overcoming the resistance of such vessels is concerned, they are able to carry enormous ordnance and extremely thick armour at 14 knots speed. The diagram, Plate II., representing the graphic illustration of similar calculations made for ships of different sizes, shows that the capacity of carrying guns and armour increases as the ships grow larger.

That answers my second question.

Neither of the ships referred to in the diagram exceeds the length of the *Inflexible*, carrying only four guns, and the draught of the largest ships considered does not surpass several existing ships, carrying incomparably less powerful guns and very thin armour. With respect to the steadiness of platform and the sea-keeping capabilities of such armoured fortresses, these can be judged of by the performance of the *Novgorod*.

In answer to Mr. Jamieson, I have laid particular stress in my Paper on the considerations which induced us in our Navy to adopt the circular form, namely, the principle of broadening and shortening ships. Also, I referred particularly to the plans of broadening ships, cutting them longitudinally. That I hoped would show in what way Admiral Popoff's labours were directed.

Admiral Popoff, after the design of the first small circular boats were got out, saw Mr. Elder's sketch in

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Engineering, but neither then nor ever considered that such a ship could be of any use for our purpose; because from that sketch it was at once evident that such ships had not enough displacement, and would draw too much water.

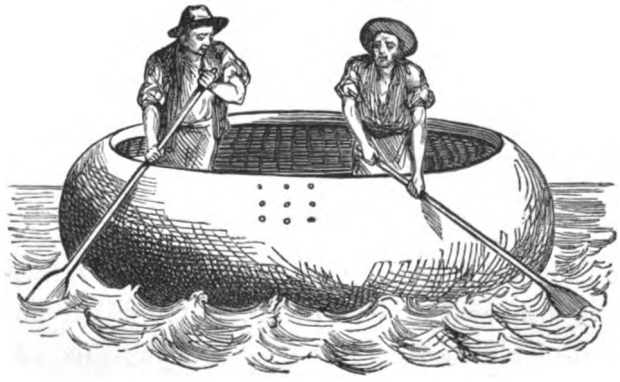
Admiral Popoff never knew of Mr. Elder's idea as to the flat-bottomed ships, and has never known about his specification, drawn for a patent, before it was published in the *Times* a few weeks ago, by Messrs. Elder and Co. If Mr. John Elder really had entertained any idea of building such ships for Russia, as stated in the *Times*, then surely he would have shown the model of her to Admiral Popoff. As it is, we never could have wanted a ship of 16,000 tons, because the largest then existing Black Sea dock could only have lifted a vessel of 2,400 tons, with a width of 120 feet.

The following is the translation from *Herodotus*, Book I., chap. 194, laid on the table by Mr. J. Scott Russell:—

"The boats which come down the river to Babylon are circular and made of skins. The frames, which are "of willow, are cut in the country of the Armenians, above Assyria, and on these which serve for hulls, a "covering of skins is stretched outside, and thus the boats are made, without either stem or stern, quite round "like a shield. They are then entirely filled with straw, and their cargo is put on board, after which they "are suffered to float down the stream. Their chief freight is wine, stored in casks made of the wood of the "palm tree. They are managed by two men, who stand upright in them, each plying an oar, one pulling and the "other pushing. The boats are of various sizes. . . . Each vessel has a live ass on board; those of the "larger size have more than one. When they reach Babylon, the cargo is landed and offered for sale, after which "the men break up their boats, sell the straw and the frames, and, loading their asses with the skins, set off on "their way back to Armenia. The current is too strong to allow a boat to return up stream, for which reason they "make their boats of skins rather than wood. On their return to Armenia they build fresh boats for the next "voyage."

The date of Herodotus' visit would be about B.C. 450 or 460, *i.e.*, not less than 2,300 years ago.

NOTE.—*See* various annotations in Rawlinson's edition of *Herodotus* translated. The modern boats of this description are navigated in the same way, but are said to be coated with bitumen instead of skin. They are called "kufa." The accompanying sketch shows the shape of the kufa, and the attitude of men in her.



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ON A PROPOSED CELLULAR SYSTEM OF BUILDING FOR SHIPS OF WAR.*

By H. J. Boolds, Esq., Surveyor, Lloyd's Registry of British and Foreign Shipping.

[Read at the Seventeenth Session of the Institution of Naval Architects, 6th April, 1876; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

Eleven years ago, in February, 1865, I read a Paper before the Scottish Shipbuilders' Association on "Cellular Ships of War," in which I advocated the sub-division of such ships into a greater number of water-tight compartments or "cells" than was then usual, or, so far as I was aware, had ever been contemplated in naval construction in this or any other country.

My object was to make the ships of our Navy unsinkable either by shot, ram, or torpedo; and, considering the excessively expensive character of a modern war ship, and what I may call the excessive facility with which ships could be sunk by either means, I believed I was doing the country some service by offering to our naval constructors a cheap and simple solution of the difficulty of keeping an iron-clad afloat and efficient in spite of all the accidents of naval warfare.

Notwithstanding the important changes that have taken place since then, in the power and size of guns, thickness of armour, and the science, if not the practice, of torpedo warfare, no attempt has been made, either on my plan or any other, to give our ships of war greater safeguards from sinking; and the internal hold arrangements of the war ships of this country are still—like merchant ships, which are intended only for facility in stowing and discharging cargo—constructed in compartments large enough singly to sink any ship, in the event of perforation from any cause. This has long appeared to me an anomalous state of matters for which there is no accounting.

As a matter of calculation and fact the whole business of a war ship is to keep herself afloat while she sinks or otherwise destroys her antagonist; but, while the science of naval warfare has been directed to destruction by every means, and protection only from

* Received 15th January, 1876.

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shot and shell, nothing whatever has been done for protection from the ram or torpedo. The power of the gun has been so much increased that the thickest armour that can be made and carried afloat is comparatively valueless for protection from shot, and worse than valueless for protection from sinking.

If, therefore, a ship, even without armour, could carry her guns and fight without risk of being sunk, she would be a much more formidable antagonist than any ship of war now in existence. There is no reason that I am aware of why all our ships of war should not be of that character. All are now built chiefly of iron and propelled by steam; their stores of every description are calculated in proportion to their armament and steam power; and the spaces in the hold are allotted and partitioned in some irregular way for the respective details of the equipment.

Now, with the exception of the machinery, which necessarily occupies large spaces, and perhaps of coals, which may require to be frequently taken in and consumed in large quantities, there is no part of the stores of a ship of war that may not be stowed in the smallest separate compartments into which I propose to divide such ships, without being in any way inconvenient to get at in emergency; even the machinery may be so divided that it may be in several water-tight compartments instead of as at present usually all in one, and there is no particular reason why coals may not be stowed in smaller separate compartments than customary, which may be emptied in detail, and closed water-tight when empty.

The recent sinking of the *Vanguard* by the ram of the *Iron Duke* has induced me to call public attention again to the system of cellular sub-division, which I believe to be the only adequate safeguard against underwater damage.

All iron ships have some bulkheads, usually limited in sailing ships to one collision bulkhead at the bow; screw steamers have, in addition, one or two whole or partial bulkheads at the stern to protect the body of the ship from danger through accidents to the screw, shaft, or pipe; and two bulkheads generally enclosing the machinery, boilers, and coals. These are all that are considered absolutely necessary against usual sea risks; the holds being required to be as large free spaces as possible for general cargo purposes.

In large and long vessels the two principal holds may be again divided by bulkheads into two spaces before and two abaft the engine room; thus separating the largest ships into seven, or, at most, eight water-tight compartments, injury in any one of which is usually sufficient to cause a total loss.

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For the necessities of cargo and trade smaller sub-divisions would be seriously inconvenient, and are, therefore, not desirable nor recommended. But although ships of war are not generally divided into a greater number of water-tight compartments than merchant steamers, there are no considerations of cargo or stowage, or of dispatch in loading and discharging, to weigh for a moment against the dangers which a ship of war—from the very "reasons for her existence"—is bound to encounter, and which she ought, therefore, to be guarded against.

In the larger iron-clads, partial protection from bottom injuries is obtained by an inner skin of iron riveted and made water-tight upon the inner edge of the floors and frames to the height of the upper part of bilge or lowest deck. The value of this inner skin has been proved in the cases of the *Great Eastern* and the *Agamemnon;* but beyond this the holds of a man-of-war, though usually as large and open as the holds of a merchant ship, are not required for any purpose but the stowage of her own consumable stores—coals, water, provisions and ammunition. Some bunker divisions have to be made for coals. Fresh water for the use of a large crew, though required in large quantity, amounting to several hundred tons, is not generally carried in tanks exceeding ten tons capacity each, which occupy a considerable space of the hold of every man-of-war. Provisions have to be stored in barrels, and store rooms built for the purpose; while magazines for ammunition, shot and shell, and other necessaries, are all divided into quantities and spaces, limited for convenience and safety into the smallest manageable proportions.

It therefore appears to me self-evident, that it would be an immense practical advantage to the ship, if the spaces into which it is absolutely necessary to separate the stores of every kind by divisions, which are now of no other use than simply as partitions, and which only add their own weight to the weight of the stores for no benefit to the ship, were enclosed by regularly-divided and permanent water-tight partitions, which would serve all the purposes for which tanks, store rooms and magazines are now required, and contribute, in proportion to their number and arrangement, to the strength and safety of the ship, instead of being, as at present, merely dead weight, increasing the risk of her destruction.

In the accompanying drawings I have shown, firstly, the composite cruiser, designed to illustrate my Paper of eleven years ago on "Cellular Ships of War;" and, secondly, the *Vanguard*, enlarged from drawings which appeared in the *Engineer* of 10th September, 1875, but with the lower holds altered and divided on the cellular system, to show how easy it would have been to have rendered that ship unsinkable, and how easy it would still be to make the rest of our ships of war much stronger and unsinkable, without

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impairing their efficiency otherwise in any respect. In the *Vanguard* plan I have shown the orlop beams lifted about 2 feet to bring this deck about 1 foot above the load line, and made a complete iron deck. The inner skin is carried up the inside of the frames and attached to this iron deck, making a complete inner ship. A longitudinal bulkhead is run through the centre line of ship from the keel to the gun deck, or deck next above the load line. All the principal transverse bulkheads are carried up to this deck, and additional bulkheads are put in, dividing the holds into spaces 24 feet long, making the spaces between the gun and orlop decks about 24 feet square.

Below the orlop deck the holds are again sub-divided by longitudinal and transverse bulkheads into spaces about 12 feet square, all fitted and caulked water-tight between the deck and the inner bottom, and from each other, there being no openings into these cells except by an iron water-tight door on the orlop deck, each space between the gun and orlop decks opening into four cells.

In an original design it would be intended to carry each of these 24-feet cellular spaces to the outer skin, thereby confining the water between the two skins to that space, with one water-tight opening in the inner skin for access to the frame spaces for cleaning and painting.

The engine room—from the design as a twin screw steamer—occupies one 24-feet space each side of central line, the next space before that being four coal cells, each 12 feet square; then a 24-feet boiler space, then four coal cells, then 24-feet boiler space, and then 12-feet cells from that to the bow—those next the forward boilers being used for coals; each cell will hold 50 tons of coals, and each group of four will hold 200 tons. Three groups on each side will hold 600 tons, or 1,200 tons of coal in all, with very little more inconvenience in trimming than ordinary bunker arrangement for such ships.

The after-end of the ship would be sub-divided in the same way, the cells through which the screw shafts pass being made tight around the shafts by stuffing boxes; the lower part of the cells through which the shafts pass can also be floored over the shaft, with access from the cells. All the cellular divisions are large enough for store rooms for all purposes, and being water-tight, will serve as tanks for water, and can be filled in groups wherever required for that purpose.

The whole of the bulkhead cellular divisions in such a ship as the *Vanguard* would not exceed 500 tons weight, and as the weight of armour above necessitates as large an amount of ballast in such ships, the whole of this ballast would be saved, and the strength and safety of the ship would be immensely increased, without adding anything to the draught of water or displacement.

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The point A on the plan is assumed to be the place where the *Vanguard* was struck by the ram of the *Iron Duke*, as the worst possible place on which she could be struck to do the greatest injury, upon or so near a principal bulkhead that the space before and abaft would fill with water.

As a cellular ship, according to the drawing, the water would be confined to the one engine room and one or two cells adjoining; but even assuming that all the bulkheads of the adjoining cells were so much started as to make them leak and fill, the whole of the water in 48 feet of length, half the breadth, and the height of the orlop deck, would not exceed 650 tons, and would not sink her more than 2 feet deeper in the water; while, with one engine and all her boilers intact, she would be perfectly safe to go anywhere for repair, and even had the *Iron Duke* been an enemy, would have been able to continue the contest without immediate fear for safety or victory.

Five hundred tons of iron judiciously expended, as I have shown, on each of the ships of our present Navy, at an expense of £20,000 each, would put twenty-five of them beyond the risk of such summary accidents either in peace or war, at a cost not exceeding the price of the *Vanguard*, which, for want of this small addition, now lies at the bottom of the Irish Channel.

Without having any interest whatever in pressing this matter upon the attention of the Government and the people of this country, beyond a desire which I only share, in common with every British subject, that the British Navy should maintain its ancient supremacy, I would most earnestly recommend the immediate adaptation of the "Cellular System" to our present iron-clad fleet—either as here illustrated, or in such modification as our naval constructors may consider advisable—as the only system upon which any approach to safety or protection can be obtained against the underwater dangers of the ram or torpedo, the use of which are now inevitable in future warfare.

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DISCUSSION.

Mr. J. D'AGUILAR SAMUDA, M.P.: I will just take this opportunity of saying that the principles contained in this Paper are such as I think must be generally approved. Without going into the details, there can be no question that directly it is admitted that it is necessary for any part of our service to possess a large quantity of unarmoured ships, that anything which can be introduced to add to their safety so enormously as the cellular system properly carried out would, must be the right thing to adopt. Of course there are a great many objections that would have to be obviated or encountered in the way of cutting up the ship into a large number of small parts, but I have no doubt the object to be attained being so great, that would be got over. But I would only observe that I do not think that sufficient belief exists generally in the great extent to which this system is already carried in the Navy. It is very much more than that which is believed to exist, and very much more than people would naturally believe to exist, by reason of the *Vanguard* having been lost. But first, with regard to that which has been done since the *Vanguard's* construction. The number of sub-divisions has been very considerably augmented. I believe in the *Vanguard* they came to something like 36, and in subsequent ships more than double that number, that is to say, if you take all the sub-divisions in the wing passages, the double bottom and the transverse bulkheads besides. But I would venture to say that, with regard to the *Vanguard*, supposing we had had the good fortune to have found the bulkhead doors of the *Vanguard* tight, and the dislocation produced on the side by the blow not to have extended sufficiently to have damaged the adjacent bulkheads and their doors, the *Vanguard* would have floated; the compartment to which the damage would then have been confined, would curiously enough have represented that which has been described by Mr. Boolds as the manner in which he would have subdivided his own ship; because I have made a calculation myself that if those two bulkheads between which the blow was struck on the *Vanguard* had been perfectly tight, the *Vanguard* would only have sunk 2 feet 6 inches lower in the water, and would not have involved the loss of the vessel. Altogether I have only to express my general concurrence with the views set forward in this Paper, and to say that I think they deserve every encouragement by those in charge of giving effect to the improvements which they would introduce into the general system of unarmoured ships.

Mr. E. J. REED, C.B., F.R.S., M.P.: This is a very important Paper, and one of which the principle is no doubt thoroughly sound; but I may also say it is one the principle of which has been thoroughly understood and acted on for many years past, and Mr. Samuda was correct in pointing out that the Paper fails in this respect, that it entirely underrates the extent to which water-tight divisions are carried in Her Majesty's ships. You might, from reading this Paper, imagine that a modern war ship had not a dozen separate compartments in her. The *Warrior*, which was the very first iron-clad built, had 35 water-tight compartments in the interior besides 57 others in the double bottom and wing passages, making a total of 92 water-tight compartments into which this vessel was divided. The *Achilles* had 106; the *Alexandra*, which is the latest broadside ship just now completing at Chatham, has 115. The *Devastation* is divided into 104, the *Dreadnought* into 101, and the *Inflexible* will have 135. I have a long list of Admiralty vessels here, and generally speaking I may say that the average number of the divisions into which they are separated is about 100; 97, 93, 99, 99, 92, and those exceeding 100 which

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I have mentioned. I shall be very happy to hand this list in for publication in the *Transactions*.* But I want to go a step beyond this, and to say that the difficulty in dividing the ships still further does not rest with the naval architect, and it is hardly here except in so far as we influence the Naval Departments that any difficulty lies in the matter. The real difficulty is that all these holds of the ship have to be worked and ventilated every day, and any one who has taken the trouble to read the report of the Court Martial on the *Vanguard* will find that the most important bulkhead of that vessel, that dividing the engine room from the boiler compartment, was cut ruthlessly through by some one for the purpose of improving ventilation, or something of that kind. I should very much like to know, if the hold of the ship is to be divided to this extent, how we are to deal with the ventilation and with the working of such compartments. The author of the Paper may well say that if he had had charge of the ship he would have attached so much importance to the sub-division that he would have undertaken to have got it worked somehow. But he speaks from a constructor's point of view and not a naval officer's, and it is only naval officers who have to work ships who know how far that is practicable, and how far it is not. Therefore, while I very much appreciate the advantage of having this question of sub-divisions more and more forced on our attention, and particularly by professional men, who can deal with it so ably as Mr. Boolds has done, yet at the same time I think it ought not be imagined that this is some scheme or some system which has been neglected hitherto, and which it has been reserved for Mr. Boolds to enforce on the Profession. On the contrary, with regard to the Royal Navy, I do not hesitate to say that whenever a ship is designed in the Admiralty, after the general requirements of the interior of the vessel are laid down on paper, the further step is taken of seeing how much it is possible to introduce water-tight divisions and sub-divisions consistently with those arrangements. It is a matter of daily practice with the Admiralty, and I myself am sure it must be with them—I know it is with us in vessels we have to do with, as far as we possibly can—to work in the ordinary elements of the ship for the sake of making water-tight divisions as numerous as we can, and we are not very particular to have them in that rectangular position which Mr. Boolds recommends. We extend a flat or longitudinal frame, or continue a bulkhead, and in fact we lead both water-tight decks and compartments wherever we can lead them consistently with interior arrangements. I do not say that for the purpose of depreciating in any way the disposition which we ought all to feel to carry that system further and further still. I should regret to lessen the effect of this Paper, but I am sure that the author himself, and your Lordship, would be very sorry to have it

* List of Water-tight Compartments in various Vessels of the Royal Navy.

	Interior of Ship.	Double Bottom and Wings (if any).	Total.		Interior of Ship.	Double Bottom and Wings (if any).	Total.
Vanguard ...	23	40	63	*Shannon* ...	44	32	76
Warrior ...	35	57	92	*Temeraire* ...	44	40	84
Achilles ...	40	66	106	*Devastation* ...	68	36	104
Hector ...	41	52	93	*Rupert* ...	40	40	80
Resistance ...	47	45	92	*Gorgon* ...	19	20	39
Monarch ...	33	40	73	*Minotaur* ...	40	49	89
Sultan ...	27	40	67	*Glatton* ...	37	60	97
Hercules ...	21	40	61	*Hotspur* ...	26	32	58
Alexandra ...	41	74	115	*Triumph* ...	26	40	66
Dreadnought	61	40	101	*Inflexible* ...	89	46	135
Nelson ...	83	16	99				

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inferred from what I may call an almost abstract Paper of this kind, that the Profession is at fault, and has been negligent in a matter of this primary importance.

Mr. CHARLES F. T. YOUNG, C.E.: I would just remark, that so far back as the year 1852, the late Mr. Richard Roberts, the well-known engineer, worked out very nearly that arrangement, sub-dividing everything throughout; and he published a quarto pamphlet upon it—I am sure Mr. Reed will remember seeing it—in 1862 or 1863. The idea is running still, but that shows that as far back as 1852 the subject was brought before us.

Mr. THOMAS BRASSEY, M.P.: I only wish to say, on behalf of the unprofessional audience, that I am sure we appreciate very much Mr. Boolds' patriotic exertions to bring before this Institution a subject which we all must recognise as of very great value. I am perfectly certain that the preparation of this Paper has cost Mr. Boolds a great deal of trouble, and that we all feel the value of the observation he makes at the close of the Paper, that he offers it, from a pure love of country, to the appreciation of naval architects through the medium of this Institution; and although no doubt it is quite true, as Mr. Reed tells us, that the subject has been considered, and very extensively dealt with by the Admiralty, I have no doubt that the exhortations which have been administered by Mr. Boolds in his Paper, speaking from a very large experience in the merchant navy, will be attended with great advantage to the public service, and for that I am sure the navy will thank him.

Admiral SELWYN, R.N.: I am about to answer Mr. Reed's challenge to naval officers, by saying that our old system of wing passages has already proved its value in the instances recited in Mr. Boolds' Paper; and I think most naval officers will join with me in saying that if we add to those wing passages a longitudinal division of the whole ship amidships, we should be contented with fewer transverse bulkheads than we should otherwise ask. That longitudinal division amidships necessarily limits the damage to be done to one side of the ship, which is of the utmost value in the case of a ram or torpedo, and enables us with wing passages to get at the damage, and to stop it, as far as possible, from the inside of the ship; efforts can be made to devise some means of drawing sails over the outside of the ship. Our great object is to be able to get at the wing passages near the sides of the ship, and that object, I think, can be obtained by the naval architect without much trouble. We should not like divisions into very small quadrangular spaces, simply because that would not suit all our stores, neither could we afford to put them in, and still secure perfect ventilation. After the ship has left the naval architect's hands she would be liable to be cut about, in obedience to some minute or memorandum which satisfied the conditions sought to be obtained for that occasion, but without enquiring from the naval architect who built her whether that violated any of his conditions. I think the broad principle of central divisions and wing passages would give us best what we want for our purposes.

Mr. FREDERICK K. BARNES: There are three points in Mr. Boolds' Paper which strike me, and on which I desire to speak. One of them has already been enlarged upon by Mr. Reed, and that was the somewhat unfair tendency of the Paper, to ignore what has already been done in the dividing of ships into compartments or cells. The necessity for sub-dividing iron ships, as far as practicable, by water-tight divisions is, and has ever been, to me so apparent that in fact I cannot imagine any person setting about to construct an iron ship for war purposes, without having that idea most distinctly in his mind; and, as Mr. Reed has pointed out, the very first iron-armoured ship that was built by the Admiralty was divided

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into no less than ninety-two separate compartments, or, as Mr. Boolds calls them, cells. That was one point on which I wished to speak; but I need not dwell upon it, as it has been disposed of already by Mr. Reed. The next point is with reference to the want of importance Mr. Boolds attaches to the division of merchant ships into separate water-tight compartments. That, to my mind, is a very serious matter, and, coming from a man holding an important position, is not satisfactory. I think the sub-division of merchant ships is of immense importance. So long ago as 1866, when the Committee of this Institution met to consider the risks attending iron ships, their sub-division into compartments was most distinctly insisted upon. The condition that was laid down by the Committee was this:—That it was desirable all iron passenger ships should be so divided into compartments or cells, that any two of them being filled with water, the ship would swim safely; and further, in their opinion it was absolutely necessary a ship should be so sub-divided by water-tight divisions that in the event of any one of her compartments being filled the ship should be safe. I think the carelessness with which Mr. Boolds seems to treat that subject requires to be pointed out; and I am very sorry to see that in the new Merchant Shipping Bill no provision has been made for the proper division, into separate water-tight compartments, of an iron merchant ship. The last point upon which I should like to say a word or two is with reference to Mr. Boolds' recommendations to alter the ships of the *Vanguard* type. Mr. Reed has already referred to the report of the Court Martial on the *Vanguard*, as showing that the *Vanguard* did not sink because she was not divided sufficiently into water-tight compartments, but because she was struck when her crew were unprepared. Mr. Boolds is aware that the *Vanguard* and her sisters have a certain amount of ballast on board of them. I suppose Mr. Boolds knows also, as everybody else in the room does, that ballast is not generally put in the maintop, or any other lofty position; but that it is put as low as possible in the ship, in order to reduce the quantity carried to a minimum. Now Mr. Boolds proposes to remove the ballast, and in its place to put in a quantity of ironwork in the shape of bulkheads, &c. He seems to ignore the existence of water-tight divisions already in the ship, and proposes a number of new divisions. He would, as a matter of fact, convert the ballast that is placed low down in the bottom of the ship into iron, in the shape of bulkheads, iron decks, &c. (the positions of which in the ship are high compared with that of the ballast), without altering the displacement. Having converted the ballast into divisions, water-tight decks, &c., Mr. Boolds thinks the ship is as right as she was before. Now I should like to know whether any person could have seriously thought out these alterations and really recommend them? What is proposed is, that ballast which is put into a ship for the usual purpose is removed to high positions in the ship, and is then converted into comparative top weight, and it is imagined that the ship's entity remains as before. These are three very important points, and in regard to them I say that Mr. Boolds is manifestly unfair in regard to the first, that his ignoring the second is unsatisfactory, and that in regard to the third, he could not have seriously thought of the alteration of the ship's entity which would result if the recommendations he makes were carried out.

Mr. E. C. WARREN: My Lord, at this late hour I will only detain you one moment. As a Member I feel very great interest in this Paper, as it treats upon one of the most important questions in connection with the safety of ships of war, but I am sorry to say that we hear so badly that we are not properly able to appreciate many of the Papers which are read. I am informed that the printed Papers are for the use of the Members of Council only. Perhaps I may be allowed to throw out this suggestion, whether it would not be advisable that a larger number of Papers should be printed, so that the Members who are interested in the subject should be enabled to follow the Papers as they are read in order that they may

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have the opportunity of speaking upon them. I have been connected with shipbuilding all my life, and having built some of the largest ships in our service, it was my special wish to speak on this Paper. I throw out the above observations in the hope that a more convenient arrangement may be made in future.

The PRESIDENT: Owing to the very numerous attendance there is a scarcity of Papers, but we will take care to have more copies printed at our next Session.

Mr. H. J. BOOLDS: I was hardly able to follow Mr. Barnes. Sometimes I thought he was in favour of my cellular plan, and he winds up at last by condemning it. I must say I have not been able to follow him sufficiently to thoroughly understand him. With respect to Mr. Reed's remarks upon my Paper, and the great consideration he has given the system of sub-divisions for a number of years, all I have to say is that if the advantages of cellular sub-division have been recognised at the Admiralty for so many years, it is curious that we see no evidence of it beyond the intercostal divisions between the inner and outer skins of the bottom, and the wing passages, which have been part of every official design since the *Warrior* period, and all of which seem to have been carefully enumerated to make up the number of compartments stated by Mr. Reed. The hold divisions for which I contend as my "cellular "system" have not yet received any official consideration whatever. I will ask one question, and that is, Why did the *Vanguard* sink if the system has been so long thought of? Allow me to say that it is no new subject to me, although it may be to a great many here, and there is the drawing that was submitted to the Glasgow Institution eleven years ago, and I have not altered the system one bit. I have only adapted the same principle to the *Vanguard*, to show that if she had been built upon that principle she would not have sunk as she did. With all due respect to the great consideration which the naval gentlemen here have given to this subject, allow me to ask again, Why did the *Vanguard* sink?

Mr. REED: You have asked the question twice, will you allow me to answer it? The reason the *Vanguard* went down is quite obvious. The very large doorways which exist between the engine room and the boiler room were never closed at all after the accident.

Mr. BOOLDS: In my ship I propose, distinctly, to have no openings below the load line. Now, you must understand that thoroughly. If I have openings below the load line, then I consider my system fails. I can prove to you, Gentlemen, that we can have the ship, and do all the work necessary with coal bunkers and everything else, and still not require to have any coal-bunker openings below at all; and I will do my coal trimming in a very much easier way than in nine-tenths of the ships in the present Navy. The cellular system which I advocate is, to have the only openings into the cells from the deck. As far as ventilation is concerned, in the pamphlet written by me, eleven years ago, I proposed to have ventilation by blast pipes from the engines—the pipes to be brought under the deck into these cells. But I do not look upon that as the principal object in my Paper. My object is to keep a ship of war afloat, if struck in any way. Mr. Reed said that the reason the *Vanguard* sunk was because they happened to leave the doors open. I say the only way in which you can insure safety is to have no openings below at all; and I can prove to you how I can do it without openings.

The PRESIDENT: It only remains for us to express our thanks to Mr. Boolds. I must say that what has passed to-day has only strengthened my opinion that Mr. Boolds has been touching on a very important subject. When he proposed to have no doors it excited so much merriment, that I cannot

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refrain from saying—I speak under correction if I am wrong—I believe that now in building French vessels they are extremely particular to have no openings, just as Mr. Boolds says, in order that there may be no risk of leaving them open; and they prefer the extra trouble of going up and down, and having their vessels maintained in safety on the seas. I am afraid I must request you to excuse me from presiding at the Evening Sitting, on account of public business in the House of Lords. I am very happy to say that my friend Mr. Scott Russell has consented to take my place.

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ON CERTAIN AUSTRIAN IRON-CLADS.*

By E. J. Reed, Esq., C.B., F.R.S., M.P., Vice-President.

[Read at the Seventeenth Session of the Institution of Naval Architects, 6th April, 1876; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

Having recently had occasion to ask my friend, Herr Romako, the Chief Constructor of the Imperial Austrian Navy, for some particulars of certain iron-clad vessels designed by him, and having received from him some interesting information respecting them, I have thought it would be useful to the Members and Associates of this Institution if I placed an outline of the same before them, for record in our *Transactions*. I do this the more readily as I have the sanction of that distinguished officer, Admiral Baron Pöckh for taking this step, and also because Herr Romako has for a long time been a Member of this Institution. It will be seen, I think, from the few remarks I propose to offer on these vessels, that in their case, as in many previous designs, Herr Romako has displayed that conspicuous ability and originality which some years ago induced us to record his name upon the roll of our Institution with much pleasure.

The first ship which I propose to mention, and very briefly to describe, is the new iron-clad *Tegetthoff*, now under construction at the works of the Stabilimento Technico, at Trieste. This large and admirable establishment took the contract for the hull, engines and boilers in August last. I will first give the general dimensions and particulars of the ship, and afterwards make a few observations upon the more marked features of the design. The following figures give her dimensions, calculated elements, &c. Length between the perpendiculars, 286 feet 11¼ inches; length, total, 303 feet 1¼ inches; breadth on the water-line, 62 feet 9 inches; extreme breadth to the outside of armour, 71 feet 1½ inches; depth of hold, 34 feet 9 inches; draught of water, aft, 26 feet 7½ inches; draught of water, forward, 23 feet 1 inch; displacement with the half of provisions, 7,390 tons; area of the midship section, 1,301 square feet; area of the load water-line, 14,308 square feet; height of metacentre above centre of gravity of displace-

* Received 4th April, 1876.

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ment, 14·623 feet; height of metacentre above water, 4·770 feet; distance of the centre of gravity of displacement before the midship-section, 3·356 feet; depth of the centre of gravity of displacement below water, 9·853 feet; co-efficient of displacement, 0·582 feet; co-efficient of water-line, 0·782 feet; co-efficient of midship-section, 0·82 feet; displacement of an inch immersion at the load water-line, 34·47 tons; weight of armour and backing, 2,160 tons. The armament consists of six 11-inch Krupp guns. Area of sails, 12,165 square feet. Cost of hull, estimated, £172,790; cost of engines and boilers, estimated, £81,715. Nominal horse-power, 1,200. Number of cylinders, 2; diameter of cylinder effective, 125 inches; length of stroke, 4 feet 3 inches. Griffiths' propeller, diameter 23 feet 6 inches; pitch, 24 feet; number of blades, 2; revolutions per minute, 70. Number of boilers, 4. Area of fire-grate, 850 square feet; heating surface, 25,500 square feet; superheating surface, 1,800 square feet. Pressure of steam, 30 pounds; number of furnaces, 36; mean indicated horse-power, 8,000; speed, estimated, 14 knots.

From these figures it will be seen that, although we are not dealing with a ship of the *Inflexible* (English), or of the *Dandolo* (Italian) type, in which armour of excessive thickness is placed over a central citadel of extremely limited extent we nevertheless have a very powerful ship indeed, with armour of apparently about 13 inches to 14 inches thick, and with a concentrated battery of six 11-inch Krupp guns, each weighing, I presume, about 27 tons. The ship has a belt of armour extending from the stern to within about 30 feet of the foremost perpendicular, where it terminates in a transverse armoured bulkhead, and a stout iron deck going forward to the stem at about 7 feet below water. It would appear from this that the Austrian authorities consider that a strong iron stem, supported by a stout deck near the point of the ram, is sufficient for ramming purposes; whereas in our Navy we have thought it better—beginning, if I remember rightly, with the *Rupert* and *Hotspur*—to keep the bow armour, and carry it down at the stem to considerably below the ram point. We may take it for granted, I think, that the latter, or English, arrangement would at least have the advantage of protecting the ram bow from much local damage in ramming iron vessels, and this is no doubt very desirable where ships are designed primarily as rams—as were the *Rupert* and *Hotspur*—while, on the other hand, where the ram is a subordinate feature—as in the *Tegetthoff*—it may be unnecessary to burden the bow with so much armour protection. It is worth while to observe in this connection that the Austrians, who have had practical experience of the effects of ramming in actual warfare, have in this, their largest and most powerful ship, preserved a very great length of under-running or spear projection, as shown in the diagram. The projection is 9 feet from the stem at the load water-line, and 19 feet from the stem head.

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I observe next in this ship the Austrian Admiralty have adopted an improvement in armour to which I have for a long time past attached great importance: I refer to the getting rid for the most part of great curvature. Of course armour plates, if carried round the ends of a ship, must be bent to the curvature of the water-lines, and when embedded, so to speak, in the sides of a ship of ordinary form and curvature—as has been usual in sea-going ships—they must also be bent crosswise. Now this double curvature of the plates is not only an expensive process, but it is also injurious to the armour plates in some degree. To Foreign Governments which do not make their own armour plates, and especially to the Governments of countries very remote from England, the system will further be attended by extreme difficulty in replacing plates injured in battle. This could hardly be accomplished by the slow and expensive process of sending accurate moulds to England for the guidance of the manufacturers. By so designing the ships that the armour plates have only to be curved in one direction, all these disadvantages and difficulties are practically got rid of; and therefore, in recent ships which I have had occasion to design for Foreign Powers, I have carried out this principle, and Herr Romako, in a letter to me, says:—"With your encouragement I have under-"taken to give the stern a form which enables the bending of the plates to be performed "in only one way." I believe I am right in saying that Mr. Barnaby and his colleagues at the Admiralty, as far as practicable, attend to the same thing, although it is, of course, of very much less importance in our Navy than in navies which depend upon foreign supplies of armour, and which are without machines for bending armour plates.

The next feature to be remarked in this ship is that the battery is of the projecting type, which so greatly facilitates the obtainment of direct fire ahead and astern from a midship battery without excessive recession of the unarmoured parts of the ship before and abaft the battery. The Admiralty Constructors and myself introduced this arrangement in many cases of upper-deck batteries in ships designed while I was at the Admiralty (most notably in the case of the *Audacious* class), but I do not think the same thing has been done at the Admiralty in the case of the main-deck battery. I have, however, done it myself in several ships for Foreign Governments, since I left the Admiralty; and I give examples in Figs. 1 and 2 (Plate IV.), which represent outline sections of the *Kaiser* and *Deutschland* (German), and the *Almirante Cochrane* and *Valparaiso* (Chilian) armour-clad ships. I cannot recal to mind any previous cases in which this has been done, or even proposed, for main-deck batteries; but it probably was at least proposed before, and I have a vague recollection or impression that Captain Symonds or Captain Scott once suggested it. My present object is, however, simply to say that in adopting the system I consider that the Austrian Admiralty have acted wisely, for it has many very great advantages, and no disadvantages of any moment that I have been able

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to discover even in a sea-way. If Mr. Barnaby and his colleagues will excuse me for saying so, I think the *Alexandra* might have been improved by these means; for in her the fore-and-aft fire has only been secured by an enormous depth of recession of the sides beyond the battery, and a corresponding contraction of the upper deck, and other accommodation. In the *Tegetthoff* the overhang is very low and considerable in amount, the battery projecting between 4 feet and 5 feet, the spread commencing at 18 inches above the water and terminating at a height of 6 feet.

A still more novel feature—one which, although I have seen it suggested before, has never yet to my knowledge been carried out—is illustrated in Fig. 3 (Plate IV.) It consists in depressing the sides of the ship into curved indentations in wake of the guns, as there shown. The object mentioned to me by Herr Romako, as that which has been sought in the arrangement, is the protection of the gun-muzzles. In mentioning the general form of the battery, and more particularly this feature, he says:—"The ship "*Tegetthoff* is in many regards a novelty, its casemate allowing an all-round fire, avoiding "at the same time, by its particular form, the dangerous projection of the muzzle of the "midship guns, in consequence of experiences acquired in the battle of Lissa, but which "are very little known even in our own Navy." It will easily be seen that in addition to the advantage assigned, this depression of the port likewise possesses the advantage (if designers chose to avail themselves of it) of affording increased horizontal training for the guns, by bringing the pivot in from the line of the ship's side; and as the armour comes in with the pivot, this end is attained without that enlargement of the port which would otherwise attend it.

The Plan in Fig. 3 (Plate IV.) shows that the *Tegetthoff* is also to be furnished with a transverse bulkhead abaft the foremost gun—an arrangement which will prevent the battery from being raked in chasing. This improvement exists in the *Alexandra*, where it was, I believe, introduced for the first time by the present Admiralty Constructors. The foremost bulkhead of the battery is inclined forward at a considerable angle to within about 4 feet of the middle line, where it becomes transverse, as shown. Immediately over this foremost portion of the battery at the middle is a very strong pilot tower, standing well up above both the gunwale and the forecastle. This shows that the Austrian officers, who have been in action with iron-clads, do not consider such towers unnecessary.

The above appear to me to be the principal features of the *Tegetthoff*. It may be interesting to add that while the outer skin and angle irons of the hull are of iron, all the remainder is of Bessemer steel, varying in tensile strength from 30 to 33 tons per square inch of section, and possessing this, as I am informed, in combination with 25 per cent.

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of ductility. This Bessemer steel is produced very successfully in Styria and Carinthia, from which districts of Austria the chief supplies for the *Tegetthoff* are derived. I may further add that in designing this ship much consideration has been given to securing both strength and sub-division, by means of water-tight bulkheads between the coal spaces and the boilers and elsewhere.

I have not hesitated in describing this ship, as above, to mention its various novel features in relation to similar improvements in our own Navy where these have taken place; because the whole design, with its many meritorious novelties and combinations, seems to me to reflect the utmost credit upon Admiral Pöckh, Herr Romako, and other Austrian officers who have been consulted, and who have taken part in the preparation of it. It may also be said in this connection that as the primary duty of a naval designer is to produce the best possible design for his employers, so his success and his merit result from the accomplishment of this great object rather than from scheming improvements merely for the sake of displaying originality. I trust this Institution will concur with me in thinking that our thanks are due to the Austrian Admiralty for enabling me to describe, at least in outline, their newest and most important iron-clad ship. Perhaps I ought to say, with reference to the very low estimated cost of the *Tegetthoff*, that the sums which I have given do not, I believe, provide for anything more than the bare hull and engines.

In conclusion, I may mention a very striking instance of conversion which has taken place in the Austrian Navy, to which I made a slight reference recently in Parliament. When last at Trieste I was much interested in finding that certain wood-built iron-clads of an early date—the *Kaiser Max*, the *Prinz Eugen* and the *Don Juan*—were being taken to pieces, with the object of replacing the wooden hulls with hulls of iron, advantage being taken of the superior lightness of the iron hull by providing for a considerable increase of armour strength in vital places. The original engines and most of the fittings of the wood ships are being used in the iron ones, and I learn that this object is being carried out with great economy. Herr Romako says:—"With the reconstruction " of the three armour-clads of the type *Kaiser Max*, the Austrian Navy has maintained " her rank as a maritime power, while for the same money we could hardly get but one " ship like the *Albrecht*, about the same as the English *Triumph* class. It is true that " the engines of the three old ships cannot give a higher velocity to the new ships than " 12 knots, but instead of only one ship we now possess three rams—the most dangerous " and secure weapons, I consider, and compared with which the action and effect of the " aggressive torpedo is, in my opinion, doubtful and insecure, and may easily endanger " the ships of its own fleet."

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The Evening Meeting of Thursday was presided over by JOHN SCOTT RUSSELL, Esq., F.R.S., Vice-President, who said:—Gentlemen, in opening the Proceedings of this evening, on the subject rather of mercantile ship construction than any other, I may merely refer to the Meeting of this morning, in which most valuable Papers were read, and most important Discussions took place on the seaworthy construction, seaworthy equipment, and seaworthy condition of ships of war. No doubt the conditions of ships of war and the conditions of merchant ships are, in many respects, materially different. There is one point, however, which is going to engage your attention this evening, and which point I think equally important for the seaworthiness of merchant ships and the seaworthiness of ships of war, and that is the quality of the materials and workmanship of which the ship is made up; for, if your materials are bad, and your workmanship unworthy, I need not say, that, whatever the other elements of the ship may be, the result must be unsatisfactory. The last Paper which was read this morning on ships of war is equally applicable to merchant ships. It was a Paper in which the author explained to us the system on which he thought ships of war might be constructed so as to offer the greatest possible resistance to the sinking or the injury of the ship, either by collision with other ships, or by injuries from the sea or the sea shore. The author of that Paper recommended a system of construction, which system of construction has recommended itself already to the constructors of ships of war; but not yet, perhaps, sufficiently to the notice of constructors of mercantile ships. What this gentleman, Mr. Boolds, in his Paper on "Cellular "Ships of War," recommended to us, was what already we had learnt, with pleasure, had been adopted in a great multitude of Her Majesty's ships, namely, the division of the interior of the ship, as far as possible, into separate water-tight compartments, and the arrangement of those water-tight compartments, as far as possible, in such a manner as not to interfere materially with the practical uses of the ship. We are going to have a Paper this evening, which is very important, as to the nature of the iron and the tests it should be submitted to, and the nature of the workmanship and the tests it should be submitted to, for the purpose of rendering an iron ship as seaworthy as possible. I am going to take the liberty, instead of reading a Paper, merely to communicate to you the results of a long series of experience and experiment on this subject, which I hope may assist shipowners in becoming owners of more seaworthy ships, and shipbuilders in building more seaworthy ships; and I hope, in both cases, without increased expense or much inconvenience. Allow me, then, to say to you, that I think a long course of experience has taught me—I think that careful experiments have satisfied me—and I think that recent experiments made by one of the worthiest experimenters in London, Mr. Kirkcaldy, have shown this remarkable, and almost, I think, new fact, that a continuous plate of iron is of far greater strength and durability, with a given quantity of material, than any combination of pieces of iron that has yet been invented by the most ingenious engineer or the most ingenious naval constructor. I will give you, as the result of my experience, this fact:—Engineers have fancied that they may make a very strong combination when they manufacture a very ingenious truss, or bridge I will call it. Now I will illustrate what, I think, is the fallacy in that. Take a bridge, if you like, 60 feet wide, and we will say 5 feet high. If this bridge were constructed by a very refined, intelligent and clever engineer, it would probably be made of a most ingenious combination of diagonals and perpendiculars; and, in examining into this, you would find that every one of those parts of which this is made up was most exquisitely proportioned, and of totally different sizes from each of the others, and each of them proportioned in the most admirable way to stand the peculiar strain which it was intended to stand; and probably you would find, as a railway

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bridge, and as a railway bridge alone, it would carry the heaviest train over with the least weight of materials. One of the points which satisfied me very early that this was, for certain purposes, a very dangerous kind of construction, was this—that I happened to pass through France during the war, and I saw a great many bridges ruined during the war—some by the shot of the enemy, and some by the explosives which the inhabitants themselves had put under the bridge when they were retreating before the enemy—and I found that the moment, in one of those bridges, you moved a single part of the bridge, the whole bridge immediately crashed to the bottom; and I give you this example of a beautiful railway construction, in which, if you will only spoil any one single point, the whole bridge crashes to the bottom in a moment. Now, all our ingenious engineering projects are of this nature. I am not going to propose to you a more ingenious plan than theirs; but I do tell you that a far less ingenious plan than theirs is infinitely more effectual in every shape, and more endurable under all unforeseen circumstances. If you will throw aside all these clever, ingenious mechanisms, and will merely roll one large plate out to the full size of this—or, if you cannot do that, rivet several large plates into one large continuous sheet—you will find that, instead of that being a weaker, it is an enormously stronger structure. I say to you, that if I take a plain sheet of ½-inch iron, and put it, say 3 feet wide, *there*, and another plain sheet of ½-inch iron *there*, and another plain sheet of ½-inch iron in that way [*describing it*], those three plain sheets of iron, extended to these lengths, are more durable and much cheaper than all these beautiful and ingenious mechanisms. You will, perhaps, ask me the reason. It would be very long to give you all the reasons for this; but I will try to give you, as near as I can, some of the reasons. Now, the sum and substance of all these reasons is this—that, when you take the continuous plate, you have an infinitely greater quantity of material helping you than when you make all these separate pieces. Now, the reason is this. Observe that *this* particular bar of iron gets no help in the work it has to do from *this*, its neighbour—none whatever; and if you annihilate *this* piece of iron, all the others tumble to pieces. What is the nature of a continuous plate, as distinguished from this series of diagonal trusses? It is this. My continuous plate has not only belts in *that* direction, and belts in *that* direction, but my continuous plate has trusses in *that* direction, and in *this*, and it has trusses everywhere. What has my continuous plate compared with this, excepting that all of *these* are filled up with continuous trusses, and all *these* are verticals, and all *these* are horizontals, and all *these* are diagonals [*describing it by an illustration*]; and the whole would be one continuous sheet, and every line that you can conceive to be drawn through it is there already. What is the consequence? The consequence is this. I send a shot through *here* [*describing it*], and what harm does it do? Nothing. All the bits of iron round it remain in the same place, and they may do for it what it has ceased to do. And, therefore, if you take this continuous sheet, and fire a cannon ball through everywhere, and damage it in the best way you can everywhere, you will find that what remains is still tough, is still strong, and is still doing its work approximately as well as it did before. I cannot occupy your time by going into this further; but I will merely ask you to take it on my authority, that a continuous plate acting as a girder is infinitely stronger than any number of patches and pieces, however ingeniously brought together; and it is so because every bit of the plate helps every other bit. Now I ask you, if, instead of ruining this by firing a cannon ball through this point, I had a plate, how could I ruin the plate?

Mr. MARTELL: May I take the liberty of asking what question is before the Meeting?

The CHAIRMAN: There is no question. There is a continuous plate, and this continuous plate might have been completed in this manner. It might have been put out of shape, but when so put out

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of shape it would practically and approximately do its work as before. Now, the conclusion I wish you to draw from that is this:—I believe that the best structure for a merchant ship is a structure of which the greatest possible quantity is made of continuous plates of iron, connected by just so much of angle iron as will unite them into one continuous whole. I believe that cross bulkheads, and longitudinal bulkheads, and horizontal bulkheads, when all put together in the structure of a ship, make a far stronger ship than any other combination; and as we have now had in two Papers, which were read to us this morning, conclusive proof that the introduction of a multitude of bulkheads into ships of war has become indispensable to their security, and as I am firmly convinced that the introduction of a number of interior bulkheads into merchant ships is a more powerful way of rendering them seaworthy and unsinkable than any other method I know, I now call attention to this fact, that if you wish to make unsinkable merchant ships, you have only to study how you can introduce the greatest quantity of bulkheads, longitudinal, transverse, and horizontal, into those ships with the least possible inconvenience for the loading and unloading of the ships. If you will do that, I believe you will have, if you use good iron, the strongest and most seaworthy ship out of the most moderate quantity of iron. What I have now said to you is intended by me to serve as a favourable introduction to the Papers which are now going to be read to you, and which will, each of them I believe, treat of some analogous question to this; and I hope that some of the Papers of this evening will lead you to see how ships of the most seaworthy character can be constructed out of a given quantity of iron and a given quantity of money. The Paper to which I alluded in the morning was the Paper on "Cellular Ships of War," by H. J. Boolds, Esq., Lloyd's Surveyor, and he explained how he would arrange those partitions so as to give the greatest possible safety along with structural strength. Of course, in what I have said to you now I ought to state that much depends upon the quality of the metal. I believe the metal of which ships ought to be built should be metal with a very considerable quantity of tensile quality; that is to say, metal which allows of considerable stretching and considerable change of form without cracking; and my own impression is that it is much better to use a more plastic metal, but one which does not carry such an extreme ultimate load, than it is to use a harder and more crackable metal which will carry an extreme load, but which will not bear that through any degree of flexion or any degree of tension. I believe that may be a most important result to grow out of the Papers of this evening. I will now call upon Mr. J. E. Scott to read his Paper on "Tested Iron and Tested Ships," in which he will, I believe, treat very thoroughly of the qualities of iron of which a ship ought to be made, and of the manner in which the workmanship of the ship should be tested; and the object of my communication to you has been to let you know that, according to a set of experiments with which I am acquainted, it is practicable to get an enormously greater quantity of strength out of plating than it is out of any other structure, provided the material of the plating has the qualities which I have mentioned—plasticity and tensile force.

Mr. MARTELL: May I take the liberty, before Mr. Scott reads his Paper, of alluding to a remark which was made this morning with regard to Mr. Boold's Paper, that Members would be allowed an opportunity of expressing an opinion upon what was there stated. I wish to ask whether we shall be allowed the opportunity of making a few remarks upon that subject?

The CHAIRMAN: Allow me to say, as Mr. Boold's Paper was upon iron and testing iron, I shall be most happy to hear any observations upon the subject *apropos* to the Paper now about to be read. You will see that the two harmonize so completely that any remarks made upon the one would be in perfect keeping with the other.

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ON TESTED IRON AND SHIPS.*

By J. E. Scott, Esq., Member.

[Read at the Seventeenth Session of the Institution of Naval Architects, 6th April, 1876; John Scott Russell, Esq., F.R.S., Vice-President, in the Chair.]

The amount of discussion which has taken place lately on this very important subject has induced me to bring this Paper under your notice. Besides being of opinion that a matter of such vital interest to the public generally, and to naval architects in particular, would be placed on its proper footing by being discussed by practical men, I think we may profit by the interchange of ideas which a discussion of the Paper may tend to elicit. There have been so many proposals of late as to the testing of iron, that one is not at all sure of the ground he stands on.

In order that every one may follow me, I have here the Admiralty's latest tests, from which you will see at once the various modes they have of testing their iron. I also give you in Tables a list of some tests we have lately made on the Clyde of the kind of iron called common ship iron, as well as of some of the pieces actually tested, from which you will see the quality of the iron used, and which has been taken promiscuously from the common ship iron of vessels now building in my yard at Greenock. But even after undergoing all these uncommonly severe tests, I should have no more confidence in it than if it had never been put under a hammer, because, if you put a sharp man who knows his business at the testing, he will put almost any bar or plate through. For instance, take a bar of angle iron, and if you want to test its ductility, you have only to take the part for testing out of the centre of the bar, and this part, I can assure you, will pass almost any test you can put it to. The cause of this is obvious to any one who knows anything about the making of iron. When a bar is put through the rolls, of course it comes out red hot, and the cooling begins first at the end and gradually comes towards the centre; thus the iron in the centre of a bar is much softer than at the ends, because it retains the heat so much longer, and is on that account the most ductile.

* Received 2nd April, 1876.

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Again, if you want to test the tensile strain, you have only to take the testing piece from the end of the bar, where it first began to cool. This will, of course, be the hardest; and you will find the very same results in testing the very greatest tensile strength. The same course holds good in any iron plates—bulb, tee, or channel iron. For this reason I have no faith in tested iron in the sense of the word: in fact, I hold this mode of testing iron to be a mere farce, and nothing more or less than an annoyance to every one in any way connected with shipbuilding, and to be in the long run productive of no better results than could be brought about in the absence of these so-called tests. In this opinion I am borne out by a gentleman who is generally considered to be an authority as to iron testing. I mean Mr. David Kirkcaldy, from whose letter to the Board of Trade on the subject of testing iron, of date 14th May, 1875, No. 188, p. 102 of the Blue Book issued by the Board of Trade, I have extracted the following:—

" The Admiralty mode of testing, by bending to various angles hot and cold I consider " unsatisfactory, as so very much depends upon the mode of treatment and the skill of " the workman; and besides adding very materially to the cost of testing, it is in reality " quite superfluous."

The proper tests, in my opinion, are those that every pound in any properly built ship has withstood, *viz.*, the working of each piece. Any one who is an advocate for tested iron according to the Admiralty schedule has only to spend a few weeks about the construction of any vessel, he will then see the torture that every part has to undergo. Where the trouble lies is, that those parts that turn out bad are not always rejected, but patched up and passed off. We hear of iron being rejected because of the test piece having turned out laminated, while ten chances to one it is the fag-end of a bar that has been taken to the test. What I mean by the fag-end of a bar is that part that has passed through the rolls last, and by the time it has got through is not in perhaps the highest welding heat—therefore it becomes laminated, or inclined to separate into different layers. Then we have another lot rejected because of having too much crystal, and you will see some men looking very wise when examining a fracture, and will give you an opinion that it is very good or bad as they think, without regard to the circumstances under which the fracture took place; while every one knows that a bar broken with a heavy blow will appear quite short and crystallised, while the same bar broken slowly or with several blows will show very reedy, or one part drawn away from the other and with no crystal whatever. Another difficulty in taking tensile tests is, that one man will put through a lot of iron while another man will reject the same, for the following reason.

The sketch shows a piece of iron to be tested for tensile strain. Of course to test this fairly, the centre of the holes A and B must be in the exact centre C of where the fracture is to take place; if this is not the case, or if the centre line drawn between

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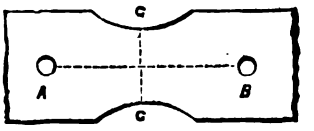
A and B happen to be placed in the very slightest on one side of the section at C, then we shall find that the iron will fracture with several tons less strain per square inch; because the centre of strain being nearer one edge than the other brings an unequal strain on the piece, or an increased strain on the edge it is farthest from, and thus brings, instead of a fair tensile strain, a racking or twisting strain, which it would be almost impossible to detect, and thereby the iron is condemned.



Tested iron has been used in many cases in the Royal Navy—with what better result no one has ever heard, only that it helps to enhance the cost of the vessels to an enormous extent; and if this tested iron clause becomes law it will only help to make ships thoroughly unseaworthy from a mercantile point of view, and instead of being, as we now are, the first mercantile navy in the world, we should be gradually forced from that proud position by the vessels of other nations, whose builders and owners had fewer restrictions. Now the first question that arises is, What is to be gained from this tested iron? In reply, all I can say is, more rust and corrosion—a ten times quicker deterioration; because it is a well-known fact that the finer the quality of iron the more readily does it corrode. This finer quality of iron will be sure to be used by makers to insure their iron always going through, and thereby insuring them against an unfair test, as the first cost of this fine quality will not be equal to the greater price they get for tested iron. In cast iron we have little or no diminution from oxidization, even when exposed alternately to wet and dry.

But from what does all this excitement on the subject of tested iron arise? Have we found the ships now afloat built of common iron, as it is called, to be bad? I think not. There is not a single case on record where a vessel came to grief through the iron used in her construction being bad. If this were the case, what should we have to say to Lloyd's and the other Registries, who know all and everything that can be known about iron ships? What are we to do with all their experience from 1838-9, the year in which the *Sirius* and *Ironsides* were built and classed, down to the present time, if they had found the quality of the iron used defective? Could they possibly have gulled the public so long by allowing bad iron, and do so still? I think the gentlemen connected with these Registries will bear me out in this, and also that when bad iron ships do turn up it is from corrosion and neglect, when they get beyond the reach of those Registries and are too good to be classed.

The decay and neglect that goes on in some vessels of this kind is beyond conception, which you may see for yourselves from specimens I have here, taken from vessels of one of the first lines that carry our mails and commerce. I have also been told by a gentleman of the highest standing in classification matters that a large vessel at Liverpool

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cost over £1,000 the other day to have her scaled or chipped; this, of course, was occasioned by the neglect and carelessness of those in charge. On hearing of this case from my friend I asked how was such a thing allowed to go on in large vessels like this. He then informed me that this was by no means a single case; and that a very great number of the large ocean steamers were allowed to go to ruin in the same way, simply from being run so hard, and no time being allowed to have the vessels properly cleaned and painted.

Some will say that this corrosion will go on even under circumstances in which the greatest care is taken. But such is not the case, as I could point out very many cases of box keelsons, and box waterways, and other parts little used, being opened after a lapse of from ten to fifteen years, and the paint inside being as perfect as the first day, and no decay whatever. This at once shows that the cause of all this decay is not from the quality of the iron, but from downright neglect. And are we, then, going needlessly to increase the cost of our mercantile navy 15 to 30 per cent. as an experiment, simply because some ships are neglected after the Registration Committees and builders have done everything in their power to make good ships? Is it not very common to hear shipowners say there is no fear of dry-rot in iron ships, and that therefore they will not need half the attention of wood ships? But I have simply to warn them that if an iron ship is not thoroughly looked after—and this is more apt to be the case every day, now that we are getting them introduced into almost all the rougher trade—the repairs to put her straight will cost far more than those of a wooden ship which has undergone the same amount of deterioration.

The other cause of bad iron ships, and one which I think the most serious of all—and in that I am sure you will all agree with me—is bad workmanship. This is a very grave point to touch upon, but to keep it in the background is impossible. Everyone in the slightest degree acquainted with ships knows at once the differences that exist between vessels holding the same certificates of classification; it is the exception when we find a vessel with a second-class certificate; in fact, we may safely say that there is not a single sailing ship at present building or that has been built during the last few years that has not the very highest place in the classification books. (The second class is principally held by steamers for a particular trade and of extreme dimensions, for if put into the first-class they would have to be made extremely heavy, and their dead-weight capacity would be considerably decreased.) But what do we find? That they are really as unlike one another as possible. The difference is not apparent when the vessel is finished, fitted out, and ready for sea; it is after the end of a first, second, or third long voyage that we find the cloven foot beginning to peep out. After the strain and pressure of storm and dead weight through that period has been sustained, we find a very little

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slackness here; a little showing of butts at the sheer strake, bilge keel and stringers; deck seams, which we find on examination to have little or no oakum in them, and which of course allow the water to get at the stringer-plates, beams, &c., and at once decay sets in. Again, we find ceilings only half bolted, with seams you could put your fingers through, but for the accumulation of dirt that prevents it; cement that has only been half put on at first; we find a mass of sand and mud choking the limbers; and that which was to have preserved the ship is the first thing to advance her ruination by the rolling from side to side of the *débris*. Then in the ends of the vessel what have we? Scarcely a landing or a breasthook that has a sound rivet in it. It has often been necessary to almost re-rivet and fit from the main deck to keel, and have extra fastenings put in, to make up for their apparent weakness, which in nine cases out of ten is caused by bad workmanship.

There are vessels at this moment on the Atlantic service doing the same work, carrying the same cargoes, and of identical dimensions—the one what is most properly called a weak vessel, and the other strong and staunch. Let us look for a moment at their construction. What is found to be the weak vessel has $\frac{1}{16}$ inch in some parts, and $\frac{2}{16}$ inch in others more plating, $\frac{1}{2}$ inch more frame, and reverse $\frac{1}{16}$ inch on floors, and keelsons proportionately stronger; in all about 10 per cent. more iron, nearly equal to 100 tons—and yet there is found the greatest possible difference. The light ship has never shown a weeping rivet, or marked a butt, while the other is constantly being caulked up and fixed off, and undergoing some repairs or other; and her sister ship has not had a rivet taken out or caulking tool applied in the ten years they have now been at work. All this weakness is from defective workmanship. In the light ship every rivet was as sound as a bell, not a single jar could be felt. This can only be had when the plates are properly fitted, and not thrown on—this is the only term I can apply to the fitting, so-called, of some vessels. In the bad vessel there never was that amount of slackness that would enable you to condemn the riveting, fitting, &c., thereby enabling the vessel to be handed over; but still the weakness was there, and could be at once appreciated by a man who knew what work is.

We hear every day people say they think vessels are far too light now to what they once were in the classification books. This is not the case, I can assure you; it is a perfectly false impression, as will be seen from the Paper read here last year by Mr. John. Since then I have worked out many cases, and have found them coincide with his estimate; and I believe this diminution of weights might still go on if we were to get correspondingly greater care of our ships from decay and conscientious workmanship. Now, from all that has been said in public and private on this matter of testing iron, it is quite clear that there is a screw loose, or rather there is one

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sometimes; and with all due deference to Mr. Reed in his proposal for testing iron, it is quite evident that his arrangement is not a popular one, as is shown from the Blue Book issued by the Board of Trade last year, before referred to, containing letters from all the practical men and firms in the kingdom in any way connected with ships and shipbuilding. I find from it 36 for and 120 against, and 35 neither for nor against; and seeing we, one and all, seem to think more or less that some kind of test or safeguard is necessary, I now propose that not only should every different piece of material that goes into a ship, but also that every bit of workmanship should also be tested, and this while the ship is in course of construction; and instead of this half-and-half staff of what are called inspectors, give us a properly qualified staff—say of one or two men to each yard, according to the tonnage building—and have them to look at everything that is put into a ship from keel to truck. This could be quite easily undertaken by the Registry by their doubling their staff and increasing their fees, and then shipowners would have vessels really good in workmanship and material for less money than they at present pay and with half the trouble, annoyance, and waste to the shipbuilder that he at present suffers from the ignorance, stupidity, and overbearing of inspectors—in many cases men who have just left the hammer and chisel, and know nothing whatever of the proper construction of vessels; and often worse than this, they are seafaring men who know little or nothing of the structure they have had under their feet for so many years.

DISCUSSION.

The CHAIRMAN (Mr. J. Scott Russell, F.R.S.): Gentlemen, you have had a very good Paper, by a practical man, on the materials and workmanship of iron ships; and we had this morning a very good Paper on the general structure and arrangement of the materials of iron ships; and I think those two Papers together will give a range to practical comments from the practical men whom I see around me; and I shall be glad to hear what your impression is as to the general structure of ships, with a view to their seaworthiness and durability; and, secondly, what views you have as to the practicability of getting merchant ships made of better iron, and getting them made also with better workmanship. I am afraid the old days, when certain firms made nothing but good iron, and when certain firms would buy nothing but good iron, and when certain firms would allow nothing to pass out of their establishments but good workmanship, and when the names of those firms were guarantees of excellence, have passed away, and that there is hardly a test universally applicable now; but I dare say modern ingenuity will supply some method of supplementing these difficulties.

Mr. MARTELL: Before commenting upon Mr. Scott's Paper, allow me to say a few words as to the Chairman's preliminary remarks, because there may be some impressions with regard to them which

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ought to be corrected. With reference to the sketch on the black board, showing the truss principle of construction, Mr. Scott Russell referred first to that mode of construction for a bridge; and afterwards he applied it to a ship; and stated, I think, that he would strongly recommend that such a principle should not be adopted, but that continuous plates, if possible, rolled in one, should be used; and if that were not possible, then that they should be as long as they could be obtained. I do not wish to say much about a bridge, because I do not pretend to understand much about the construction of bridges; but I should like to refer to the truss principle of construction of composite ships, where we have a ship constructed with a continuous iron sheer strake some 3 feet wide, and another longitudinal strake at the bilges, and diagonal plates fitted in the manner there illustrated, secured to the bilge strakes and sheer strakes. That mode of construction has been found to be perfectly efficient for the purpose intended. Ships constructed in that manner, so far as I know, have never shown symptoms of weakness. They have been strong and efficient for all purposes, and it is an excellent mode of construction. Of course, if you are to plate a ship all over, and make an iron ship of her, it would make her still stronger; but that is not required in a composite ship, for the truss principle of construction is found to answer every purpose. I thought it right to mention this, because the Chairman's remarks referred to the construction of ships, and his observations on the point might be misunderstood.

The CHAIRMAN: I did not allude to wooden ships at all.

Mr. MARTELL: Then an iron ship could not be built the way he described, because you would be obliged to make the plates continuous to keep the water out. With reference to the remarks of Mr. Scott—who appears to deprecate tests of all kinds, as being very annoying to the builder, and, as doing no good and being quite superfluous—I expressed an opinion last Session, and am quite prepared to endorse that opinion, to the effect that we are very much indebted to the Admiralty authorities for maintaining their tests upon iron. I do not hesitate to say that the iron of the present day is very much better than it would have been at this time had there been no Admiralty supervision, and had it not been for the very rigid tests they apply to iron. It has set up the standard for quality of iron; and in that way has done good, I have no hesitation in saying, throughout all iron shipbuilding yards. At the same time I believe that to institute a Government compulsory test for all iron such as Mr. Scott has referred to would be highly injurious to the shipbuilding of this country and all interested in it. I believe that interference in that way would force small shipbuilders out of the market altogether. Shipbuilders in a small way, having small quantities of iron sent to them, and not knowing the quality of it till it is delivered in the yard, if they have to test it, and then find it unequal to the tests thus laid down, would be unable to get supplies to carry on their work. It would positively drive those small men out of the market altogether. No doubt great advantage has been derived indirectly from the Admiralty tests; and I must say, if I had to build a ship for myself, I should like to have the iron tested, if I could, to know something more of the working of it; but although I think the expense would be too great for ordinary shipbuilders, yet the Admiralty are quite right in insisting upon it, because expense to them is not such a consideration as it is with merchants; and the superiority of material is a matter of paramount importance to them. Speaking from actual experience, after having visited all the yards in the country, pretty nearly, last year, with the Committee of Lloyd's Register, and examined ships in course of construction minutely, I can say that we found the quality of iron generally used for shipbuilding purposes of a very satisfactory description—and better than we anticipated. We knew that there had

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been—during the time when an enormous amount of ships were being built, two or three years before—a large quantity of inferior material thrown upon the market; but that has rectified itself; and I believe that if the ships are carefully examined, carefully surveyed at the present time—and we have, as I fully believe we have, common honesty among the shipbuilders themselves—we shall only use a material suitable for the purpose; and, really, it would be quite unnecessary and highly detrimental if Government tests were instituted for all mercantile ships built of iron. I am persuaded it would be injurious and very wrong; and I, for one, should be very sorry to see such a thing. With regard to Mr. Scott's observations, as to having one or two surveyors in each yard, that is out of the question. No one could entertain such a suggestion as that for a moment. I am sorry to hear from him—I do not know whether it is from his own experience or what he has been told—that the difference in the quality of ships is so great as he stated. I suppose it must have been brought under his notice, in some way or other, as he thinks it is so common for inferior iron to be patched up and made good, and that the surveyors do not perform their duty—for that is what one would be led to infer—in an efficient and independent manner, and that they do not condemn inferior iron as it should be condemned. I am sorry to hear that such an evil does exist. But that has two sides; and whether he refers to the surveyors of classification for Lloyd's Register, as to the manner in which they perform their duties, or to other inspectors, I cannot tell; but I believe the quality of workmanship is a matter of great importance; and, as he said, the honesty of the builder is also of great importance; and the quality of the iron likewise is, no doubt, matter of very serious consideration indeed. If I might refer to a case, I would refer to one where good workmanship and good materials were used in the construction of some masts that were made for Mr. Lamport some twenty years ago. Those were some iron masts used in a wooden ship—large masts, and the plates of those masts were only $\frac{4}{16}$ths of an inch thick. That ship experienced very severe weather, which carried away at different times several topmasts. Still those masts did their work remarkably well, showing what good material and good workmanship will do even with light scantlings. I admit that the mode of construction which Mr. Lamport adopted in the matter shows, as Mr. Scott has also said, that much lighter materials can be used where the workmanship is good and the material is good. But I remember some cases, such as Mr. Scott has referred to, of some light ships built in the Clyde by an eminent firm. He said that light ships did remarkably well, as compared with the heavy ships; but the fact is, that the light ships have been always undergoing repairs, and wanting strengthening, and have never done their work properly. It is all very well for builders to talk about this great efficiency with light ships, but you must draw the limit somewhere. You cannot have strength, even with good material and good workmanship, unless you have a certain quantity of iron as well. You must have the three combined. I make these remarks because I was very much interested in hearing Mr. Scott's Paper, and I hope that all builders may try to turn out a ship as fairly and honestly from their yards as he does.

Mr. CHARLES LAMPORT: While listening to Mr. Scott's Paper, and to what has since fallen from Mr. Martell, I wished that Mr. Plimsoll had been present, because he would have heard what he might have considered strange doctrine. He would have heard that as to one of his favourite aims, saving life at sea, the testing of plates was not a panacea so perfect and universally to be applied for that evil as he supposed. I think he would have been astonished when he heard a gentleman of Mr. Martell's large experience say that the quality of our iron generally was at the present time fairly up to the mark. If in the present day the quality of the iron is very good, and if to ascertain this tests cannot be fairly

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and with justice applied, the great question is, What are we, as shipowners, to fall back upon to produce a feeling of faith and satisfaction in the ships that we buy? I say now, as I have said ever since I began to have anything to do with ships, that if any shipowner goes upon any other principle than the character of the shipbuilder with whom he deals, he will be traversing a quicksand. Gentlemen, I am sure I shall not be travelling out of the record if I allude to the legislation which is to ensure iron being good and ships being built in the proper way. The Government have introduced a measure with regard to the seaworthiness of merchant ships, and already 213 amendments have been announced upon that measure. You will remember that that measure has been concocted after twelve months' careful examination and careful consultation with everybody believed to be experts in this important matter. The Government brought in their Bill in 1875 as a temporary measure. Previously to that they had made enquiries, but they were not satisfied, and Mr. Plimsoll defeated them, as you all know, by a surprise, and in fact routed them with scorn and disdain in the House of Commons last Session. Since then the Board of Trade officials have been travelling about, I believe, to every large port and consulted the owners of ships and shipbuilding yards, and they have now produced in the House of Commons a Bill that must be held fairly to represent at least the matured judgment of the Board of Trade, supplemented and supported by the suggestions of, we must suppose, the greatest talent of everybody holding the same opinions as they do throughout the country. What was the result? The first night the Bill was laid upon the table of the House of Commons there were 213 amendments announced. Now, Gentlemen, can anything show more clearly, not that it is not a well-matured question, but simply and solely that it aims at dealing with a subject that legislation cannot touch or compass, or have an effective influence upon? Now, going back to the Paper before the Meeting, Mr. Scott tells us that there is nothing that can ensure a good ship but good workmanship—which means, to use a popular phrase, and to chime in with popular sentiment in reference to seaworthiness, that nothing else will ensure "safety of life at sea." I believe Mr. Scott is perfectly right; but I put it to you, Gentlemen, who understand this question, as the majority of you do, how is it possible that this good workmanship can be insured? I know very well that the staff of Lloyd's Committee are men as honourable and as devoted to their work, and as freely to be trusted, and of as high scientific acquirements—I do not say as any class, but more so than any class in a similar position which I have had any experience of, or heard anything about, all over the world. I believe that nobody has brought home to them a single instance of what Shakespeare calls the "itching palm." I do not believe there was ever a case which was fairly open to discussion on a controverted point that the opportunity for appeal was not afforded. The surveyors themselves were liable, as we know they are, and as we all are—for we are but human—to err in judgment; but I do not believe that Lloyd's Committee ever rejected an appeal, based upon fair grounds, which was made to them. If they cannot effect a seaworthiness, who can? Yet at this time the Government Bill is insisting on the establishment of a staff of surveyors, as they call them, beginning with superior district surveyors and subordinate surveyors downwards, to go round and watch the manual work, which will cost not less than £200,000. For what? Not to ensure good ships. I say they cannot do that until they put an overseer in every yard, or, as Mr. Scott properly says, put a couple of them, who will go when the bell rings, to watch every rivet as it is put in, and test it afterwards, and to stay till the bell rings the men out at night, and so occupy the place of shipbuilders' *employées* themselves. If that is the case, we have pressed this matter to the *argumentum ad absurdum;* and if surveys and tests, and everything of that kind are to depend upon somebody being in the yard the whole of the time,

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then, I say, let us trust to the servants of the shipbuilder; let us make him personally responsible, and let every one who wishes to buy and have a good ship, make him give a written guarantee that the ship is sound, and if she turns out not to be so, then he should be liable to assessed and liquidated damages to the extent of the value of the ship. Then you would have something to fall back upon. You would fall back upon the common law of England which we are accustomed to, and which we know; you fall back upon character, which I dare say a great many of us know something about; and, at all events, you fall back upon the constant vigilance and the stimulus created by what alone can make trade pay—namely, the prospect of ultimate profit founded not only upon the individual ship, not only on the work done in one year, but the work that is to be done regularly. If you cannot do this—and Government practically says it cannot be done because they are going to do something quite different—then I would ask them, and any shipowner who puts engines into a steamer, whether or not they would not be perfectly satisfied to contract for a pair of engines with, say Messrs. Penn & Company, if they will give their guarantee that those engines shall be everything the shipowner can expect from them, that they will perform their work, and that they will last for a certain time? Would anybody feel any doubt about that? I venture to say, in the presence of Mr. Barnaby, that the Government themselves do not feel any doubt about that; and if the Government can trust the very heart and life of a steamer, surely they may trust that which is much more easy to deal with—the hull of the ship, which calls for comparatively so little care and perfect workmanship. If you can trust to character for the construction of the steam engine, I ask, as a practical man, why you cannot trust for good workmanship and good quality in the construction of that which calls for infinitely less care? Do the Government send workmen to survey the engines that are made? Do they send their inspectors into the manufactories where their chronometers are produced? Do they go into the places where the anchors and chains are forged? I want to know why any distinction should be made. I have nothing more to say in reference to the matter than this. I do not know whether you stand in the position I do as a shipowner, but, putting aside all considerations of profit, and everything of that kind, I look upon the working of the mercantile marine of this country, both as regards those who build and those who own ships, as a question that affects not the individual shipowner and builder so much as the general prosperity of the whole country. My calculation is that the livelihood of upwards of one million and a half of persons hangs upon ships; and I think when so much depends upon a trade of this kind, it is not to be treated in a loose sort of way and shouted down. It is a matter of life and death to the trade and commerce of this country, and to the welfare of that million and a half of persons engaged in the shipping trade.

Mr. N. Barnaby: I am not quite sure that I have thoroughly understood some of Mr. Scott's statements, but I understood him to refer to the tests for angle bars mainly, and not to plates. If he has discovered that the materials of which plates are made differ greatly in the parts that are near the end and those in the middle, I think that is an important discovery which he ought to make known to us, and give us the information on which he bases that statement. The fact is, that the tensile strength of angle bars is a matter of very little consequence, and no Admiralty overseer attaches much importance to it. If it stands the forge tests, he is perfectly satisfied with the material, and would not attach the smallest importance to the differences shown on that sheet. But if it could be shown to us that plates, which are the real things at issue, differ greatly in their qualities in the middle and at the end, that would be

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important. I should like to know presently from Mr. Scott whether he means to say that. It is obvious that if you test by making a hole for the drawing bolts in what you call the middle, you should take care it is really in the middle of the piece. Generally people do not test in that way, but they test by a clip which does not involve that source of error. It appears to me, with regard to the question of testing materials, that there is no safeguard except a final test to be applied whenever you think it necessary to apply it; and that you must, in the exercise of your own discretion, allow much of the material to pass without testing, inasmuch as you cannot possibly test every plate: that is out of the question. But somebody, either Mr. Scott or Mr. Kirkaldy, said that you always had the means of telling whether the pieces of material you put into a ship were good or bad when you worked them. Is that so? I ask any shipbuilder here whether there are not plenty of plates in a ship that never receive such an amount of work as would enable him to detect whether the plate was good or bad. I know perfectly well all our own overseers are in the habit of exercising their judgment upon it, and when you see a plate sheared, and when you see it punched (and our Chairman knows that as well as anybody in the room), you can tell pretty nearly whether you are dealing with good iron or bad; but you cannot be perfectly sure, from the nature of your punching and your shearing, whether you may not have in some cases a plate that ought not to go in. The Admiralty practice is this:—They say, "We must have some standard which "we shall apply when we like. We shall choose to allow you to put plates here, and angle irons there, "so long as we can satisfy ourselves by the work you put into them that the material is good, but "directly we say we want a test we must have the test." As I understand it, it is not the Admiralty alone that insist upon the tests, but Lloyd's surveyors do the same. How often they exercise it I do not know. That is in their discretion. I have seen a code of tensile strains in their books which may in their discretion be applied to iron, and it is bound to stand those strains. It seems to me there is no way to ensure having the ships well built, except by having some standard to be exercised within the discretion of the proper officers appointed to oversee the building of ships. It is amusing to hear Mr. Scott speaking as if there were no way in which ships could be built well except by having one or two inspectors independent of the builder himself, to see that they are well built. One would think, from what we have heard, that the credit of the builder (about which Mr. Lamport has spoken so much) would be something in the matter, as I believe it is. It seems to me that the course taken by Lloyd's surveyors is a wise and proper course. They do not test so often as we do. The iron does not cost so much money as our own iron costs; but I think that we and they would be quite wrong if we gave up the tests altogether. But now I should like to say one thing that will confirm what has been said by Mr. Martell, Mr. Lamport, and perhaps what Mr. Scott may think has been said by himself. I want to be perfectly honest in the matter. We took the trouble some time ago to purchase, from some private manufacturers of iron over the country, some iron according to a certain specification. They did not know for whom the order was given; but certain plates were all sent eventually to one spot, and there laid out side by side. It was of different prices. Some of it was a great deal cheaper than the price we were giving for that description of iron, and we were curious to know what sort of stuff it was which was called ship-plate iron, and I have to tell you that the iron was very good iron indeed. To that there was no exception, but in the matter of surface. In the matter of surface some was very bad, but in the matter of quality of material it was all good iron. But then I must say, and that may be some drawback, that it was all English iron. I confess I heard a statement some time since with regard to a fracture in the bow of a certain ship in Mr. Walker's dock, which made me draw in my horns

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somewhat. I had been speaking confidently of the excellent character of the iron of which merchant ships are built, and I was asked whether I had seen the fracture of the iron in the bow of the *Franconia*. I had to say I had not. Then I was told it was a very bad fracture, and that the bow plates showed that the iron was not good. I believe the *Franconia* was built on the Clyde.

Mr. SCOTT: Yes, she was.

Mr. BARNABY: I have nothing to say about Scotch iron, except this, that we have some ships excellently built in Scotland, but we take care to tell our inspectors to keep their tests in their hands, and to insist upon having the tests applied whenever they please, and those excellent builders building those ships raise no difficulty whatever. They do not say, "What stupid people the Admiralty are to insist "upon those tests;" but they go on, the iron passes very well, there is no grumbling, and we get thoroughly good ships built.

The CHAIRMAN: I think we have, perhaps, thrashed this subject out, and I am sure that you will feel with me that a great deal of useful information has been obtained; and the practical result of it all is very much this, that if you want good ships, you must first go to a good ironmaster who never makes any but the best iron; secondly, to a good shipbuilder, who never puts any but the best possible workmanship in his ships; and thirdly, that it must be inspected under an inspector, like one of these very superior Lloyd's, and classed with the high class, and then you may pay your money and take your property, and everybody around you will prosper, and every one of you will have done his duty. That is a satisfactory conclusion at which to arrive. The other conclusion is, that no machinery and no legislation will make good ships out of bad iron, or clever and able and conscientious workmen out of ignorant or cheating persons.

Mr. SCOTT: Of course, in writing this Paper, I simply drew the line for classed vessels, or those vessels that are insured by underwriters at Lloyd's. They, of course, all look for some qualification in the matter, and, therefore, expect to have some guarantee. That is why I did not say anything in my Paper about going to a good builder, or knowing who was building the ship for you. Of course the underwriters—speaking on the matter from an underwriter's point of view—take Lloyd's Book as their standard in deciding whether they shall put £200 on a ship or £2,000.

Mr. C. LAMPORT: I say, as a practical underwriter, that we go by character more than anything else. The firm with which I am connected, as underwriters, will not take ships built in particular ports which I will not mention.

Mr. SCOTT: Quite so; but they may not be all like Mr. Lamport in this matter.

The CHAIRMAN: You are talking of classed ships?

Mr. SCOTT: Yes. It has been spoken of lately by Mr. Plimsoll. As to Mr. Martell's remarks about the surveyors, I may say that I did not include Lloyd's surveyors at all in the matter of inspectors. What I mean by inspectors are those men who are put to superintend a vessel, while building, by the owners, and who are very ignorant often, although they are supposed to be wise, because they are practical men or tradesmen. Every man is not a good constructor of a vessel who, as a tradesman, may know how to handle a chisel and hammer; and he is not always a man who is properly qualified to look after the construction of a ship. As to Mr. Martell's remarks about light ships, I did not for a moment

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imagine that Mr. Martell would suppose that this light ship which I spoke of was a vessel bearing a greater strain per inch on any part than the iron would bear. That, of course, is the case with some of the light vessels that he has heard of being built in the Clyde. If Mr. Martell reckoned the section out, he would find that they, instead of having only a strain of 5 to 6 tons on the square inch, had from 10 to 12 tons on the square inch. Those are what we call light ships—useless ships; but the vessels I spoke of have from 5 to 6 tons on the square inch of strain—that is hogging and bending strain. Then, if we do away with this qualification, and put the responsibility on the builder, no doubt there are many builders, as well as myself, who would be at once able and willing to take the responsibility of the work they turn out of their hands. You will not find that everywhere. Owners say to us, "We can have such a vessel classed, and that class is quite as good to me as your ship; and, of course, we prefer not to spend that money upon her." That is how I spoke of the qualification. Then, as to Mr. Barnaby's remarks about the testing of plates—I mean plates as well as angle bars. Every second, or perhaps 60 per cent. of those tests are taken from plates, and you will find the results are exactly as I say. If you take a piece of iron out of the centre of a plate you will find that the most ductile part of the whole plate. Now, suppose you take the centre part of an iron plate, and test the ductility on the tensile strain, you will find the plate varies. The plate will stand 20 tons to a square inch in one part and 25 tons in another part, and so on like that. If any man condemned a plate of that kind out of an iron-maker's hands, he would immediately say, "Your test was not right; you gave me 20 tons to the square "inch in one part, 22 in another, and 25 in another; and my iron must be good, because one part of "the plate stands a higher test and the other does not." That shows the fallacy of the test. Then as to punching, I think if Mr. Barnaby were to go into the regular work of a shop, and see the punching and shearing of plates, he would at once find out whether it was a good or bad plate he was working. I have some specimens of iron cut off a common bar—an angle iron bar, that has been twisted in the cutting off, because of the head of the punching machine being close up and twisting the iron. Any one can see at once that it is beautiful iron, so that I think the working is the proper test for iron. You will excuse me, Mr. Barnaby, for saying these things, because I am a very much younger man than you are; and I am only talking from my own experience in iron shipbuilding, which I have been engaged in since I was quite a youth. Then, as to English iron, I am sorry to say that we in Scotland cannot produce the plates necessary for building ships, unless at a very much higher rate than we can get them for in England. Therefore you may safely say that two-thirds of the plates used in the construction of vessels in the Clyde are from England. As to the fracture in the *Franconia's* bow, I have heard something about that. She was constructed within 200 yards from my place; and if you took the plate that looks so bad in the *Franconia's* bow, and attempted to break it, no doubt you could break it with a 7-pound hammer, placing it over the edge of a block; but Mr. Barnaby must remember that that part of the *Franconia's* bow, before it gave way, was subject to enormous strain. The whole of the plating and the shell round the fracture was subjected to an enormous strain, thereby stretching the iron beyond its strength; and, of course, anything near the fracture must look bad. But, if you were allowed by the owners of the *Franconia* to take a plate out from the centre of the ship, you would find that the iron was as good as the iron in any other ships. I am only saying this from my own idea upon the subject. Then Mr. Barnaby spoke as if I had for a moment insinuated that the people at the Admiralty were at all stupid in demanding tests. I believe that is not to be thought of. Nobody would say that there was anything wrong as regards those tests; but only that it would not do to subject the vessels of the

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mercantile navy to those tests, because we have not that amount of money to spend upon mercantile ships which is necessary to produce vessels intended for the Royal Navy.

The CHAIRMAN: I am sure we all feel indebted to Mr. Scott, of a very eminent firm, for the practical remarks he has made to us; and I am sure Mr. Barnaby will agree that practical experience and practical views, instead of interfering with what we do, always add to our knowledge and information. We are much obliged to Mr. Scott for his views, however they may differ from our own, because I think that views which differ from our own very often correct them.

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ON DOUBLE AND TRIPLE CYLINDRICAL VESSELS.*

By H. A. Egerton, Esq.

[Read at the Seventeenth Session of the Institution of Naval Architects, 6th April, 1876; John Scott Russell, Esq., F.R.S., Vice-President, in the Chair.]

In discussing the merits of ships composed of two or more hulls, it may not be out of place, in the first instance, to consider the size of waves which vessels may be required to encounter under varying circumstances and in different seas, since it must be evident, that a vessel which might be suitable for certain waters would not, to the same extent, meet the difficulties to be experienced in others.

Another matter of importance is the consideration of the particular objects to be obtained which would render it desirable to build vessels not in conformity with the usual shape and construction.

It is by no means intended to demonstrate that for ordinary purposes the present description of sea-going vessel is not admirably adapted for its different requirements; the intention being merely to show that, for certain exceptional cases, a totally different build may not only be desirable but necessary. Doubtless, for cargo-carrying, for the purpose of entering narrow harbours and winding channels, and for rendering the wind wholly or partially available as a motive power, little improvement could be made in shipbuilding as at present conducted; but where exceptional steadiness is required, and perfect ventilation must be obtained (as in carrying live stock great distances), ships of the present day are not of the most suitable type; and even where only short distances have to be travelled by water, but by large numbers of passengers (as between England and France), it seems almost incredible that all the discomforts of a sea voyage should have to be encountered, thereby actually debarring a large proportion of our population from visiting the nearest adjoining country.

Up to the present time there seems to have been a strange disinclination to venture upon any radical change in seafaring matters; and whereas during the last fifty years we

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have seen a complete revolution in land engineering—as witness locomotion, bridges, tunnels, telegraphs, &c.—nevertheless no such corresponding benefits are to be found at sea. It is true that steam has been introduced as a motive power, but with this single exception it is hard to discover any important change which has been made, capable of being looked upon in any other light than mere modifications of previously existing systems. It may be said that we have greatly altered the material, substituting in many instances iron for wood; that we have larger ships; that their length is greater in proportion to their beam (in cyclads the reverse); that they draw less or more water; their lines vary, &c.; but these are only variations. The steamer of the present day, on its way from Liverpool to New York, is the sailing vessel of olden days, modified and driven by steam. The iron steamer still rolls, perhaps quite as much as her prototype the wooden sailing vessel, and but for her increased length, would pitch to the same extent. On the other hand, she will not steer as well. There is the same provocation to sea-sickness, the same inability to carry live stock in quantity any considerable distance. The iron steamer is subject to the same danger at sea, with possibly an increased liability to founder in case of collision, and to break up when driven ashore. Nevertheless, under existing circumstances, and bearing in mind the objects shipowners and builders have in view, the ordinary ship of the day may be the most suitable for general purposes, but it is incapable of affording to the old country the benefits of making use of the abundant herds of cattle and horses to be obtained so cheaply in America, and renders travelling by sea such an intolerable burden to the majority of landsmen as to prevent the ocean from being what it seems to have been intended for—the vast highway of the globe.

In reference to the size of waves which vessels may be required to encounter in various seas, it is not now worth while considering those of the first order; but those of the second may fairly be within the range of the subject.

Hitherto, in shipbuilding, strenuous efforts have been usually made with the object of causing both bow and stern to rise to a wave, and on looking at ordinary ships, with their small freeboard, and the extreme danger in case of a heavy sea sweeping the deck, the imperative necessity for so doing becomes evident. Nevertheless under certain circumstances this motion is precisely the one which should be avoided. Once recognise the fact that there is no *danger* in going straight through the waves, and it will readily be admitted that it will be preferable to do so, rather than rise and fall to each succeeding one. Clearly, even as built at the present time, vessels *do* go through waves without rising over them, but only when the height and length of such waves bear a small proportion to the length of the vessel placed upon them; and there are few travellers who have not experienced the heavy shock which is the effect of the

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upper portion of a head sea striking the bows of a ship pitching head downward to meet it; and it is clear that this effect is in proportion to the size and abruptness of the wave to the vessel placed thereon. When encountering small waves (in going head to wind), an ordinary vessel offers little resistance, since she does not bring the wide and consequently buoyant portion of her bows in opposition to them; but when plunging head foremost into larger ones, the very act which saves her from being washed fore and aft, effectually stops her way. The simple fact of rising over the wave is equivalent to grievously checking her speed; nor can this be avoided so long as it is considered necessary to rise and fall with the wave.

Given waves 10 feet high and 50 feet long, place on them a vessel as usually built—60 feet long, drawing 5 feet of water—and the effect of a head sea is manifest; but in the same sea place a cylindrical pontoon, 20 feet diameter amidships, tapering towards both ends, 500 feet long, and drawing 10 feet amidships, and not only will there be no pitching motion, but also the retarding force of the waves will be lost, since no *absolute* motion forward exists in waves of oscillation, the forward motion of the upper portion being counterbalanced by the backward motion in the lower; and all shock caused by the sea will be avoided: neither does this effect become limited by any increased size of the wave. Proportion in like manner the pontoon to the wave, and no matter what height the wave, pitching is absolutely destroyed, and, with it, the retarding force of a head sea; but there will be little use in altering the shape of a vessel, without a corresponding proportioning of its size to suit the waves it will have to encounter. Therefore in seas like the Channel, where the waves occasionally reach such dimensions as 13 or 14 feet, the pontoons should be not less than 26 feet diameter amidships, and for crossing the Atlantic, 60 feet.

For many years past the author has been trying experiments for the purpose of ascertaining the distance between two hulls (of a twin ship) best adapted for obtaining the greatest amount of speed with the least expenditure of power. Having previously, in consequence of numerous trials (with differently shaped models), arrived at the conclusion that the best shape to adopt was that of a cylinder, gradually tapering from the centre to both ends, length not less than twenty-five to thirty times the midship diameter, all the later experiments have been tried with two or more cylinders of this construction, and the results obtained with two cylinders have been as follows.

Taking the power required to propel a single cylinder of the proportions previously stated, at the rate of 5 miles per hour, as 1, it would at first appear as though double that power, or say 2, should be sufficient to propel two such cylinders at the same speed. With two such cylinders, connected together on the top in such a manner that the parts joining them do not come in contact with the water, and so closely that the

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cylinders touch one another amidships, the author finds that more than three times the power is required, instead of two. Further, by separating the two cylinders a clear distance of one-half the midships diameter of one cylinder, the power required falls to 3. By increasing the space between them amidships to 1 diameter, the power required falls below 3. At 2 diameters apart, 2·5 is sufficient. At 3 diameters it is reduced to 2·2; and at 5 diameters apart the cylinders cease to have any influence on each other, the power required to propel them both being exactly double that necessary to propel a single one. Hence it may fairly be argued, that the most economical distance at which the cylinders can be placed apart may be taken as being five times their midships diameter.

Having thus arrived at the most satisfactory shape for the hulls, and the most economical distance apart to place them, it becomes a matter for consideration what will be the effect of the waves upon the girders connecting the cylinders; and here it becomes evident that the strain put upon these girders must depend upon the proportionate size of the waves to the cylinders; and provided that the diameter of the cylinders is never less than twice the height of the greatest possible waves, no strain of real importance can exist, and a ship may be so constructed on this plan as to be absolutely safe from all damage by waves, if only it is made sufficiently large.

The special advantages to be derived from this form of vessel are the following:—

1.—Its extreme length, combined with the comparatively small flotation power of its extremities, renders *pitching* impossible.

2.—Its length also gives great carrying capacity, in proportion to the horse-power required to propel it.

3.—Its great beam, from outside to outside of the cylinders, combined with the clear space between the hulls, does away with rolling, reducing the motion caused by a beam sea merely to a vertical one, and (in a triple ship) very much reducing that.

4.—The great beam also is of much importance in reference to its steering powers, enabling the vessel to be readily steered by its paddles alone, and this also without having any way upon her, since a vessel so constructed will readily go round upon its own axis.

5.—The ends rising to a level with the surface of the water are also of great assistance in steering, and probably no vessel yet constructed, with the exception of the circular iron-clads, will steer so easily.

6.—The great length, combined with the tapering ends, will have the effect

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of annihilating the shock of a head sea, and preventing it from checking the speed of the vessel.

7.—The great buoyancy in the centre, as compared with the small buoyancy of the ends, will prevent the waves from lifting either stem or stern.

8.—The fact of using the cylinders for flotation only enables water-tight compartments to be used in quantity, and rendered *absolutely* water-tight; and the number which can be so used would render the ship positively safe, even though several of the compartments might be injured or even destroyed.

9.—The peculiar shape of the cylinders (a true circle) will enable the ship's bottom to be cleaned without going into dry dock, and damage in case of a collision to be temporarily repaired without any difficulty.

10.—For the purpose of carrying cattle, horses, or troops, no other vessel could be ventilated in so perfect a manner. The fact of the superstructure being absolutely removed from all possible contact with the water, renders perfect ventilation from stem to stern an easy task; and when the serious loss to live stock, arising from the necessarily imperfect ventilation in ordinary ships, which invariably attends only a short sea voyage, is taken into consideration, this subject is of the utmost importance; since to a country like England, where the breeding of horses is not equal to its ordinary working requirements, the dearth of horses, inevitable in case of war, would be a positive calamity. But when the vast herds of excellent horses in the New World are made available no such danger need be imminent.

The insufficient supply of sound second-class beef to the working population of Great Britain is so thoroughly known, that no great stress need be put upon the value of any contrivance capable of utilizing the abundant herds of Texas and the River Plate.

The one objection which will doubtless be generally urged against such a vessel as that proposed for crossing the *Atlantic*—1,800 feet long, 420 feet beam, and drawing 30 feet of water—will be that no harbours are accessible to such a ship. This, however, is by no means the case. Milford Haven is quite capable of receiving any reasonable number of such vessels, and Spithead itself is an excellent harbour for such a ship.

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DISCUSSION.

Mr. C. W. MERRIFIELD, F.R.S.: I regret to have to take up the time of the Meeting by making any observations upon this subject; but it seems hardly right to allow some of the statements in this Paper to pass unchallenged. In the first place, I may remark that the idea of this class of vessels is by no means new. I remember a dozen, as nearly as possible, approaching this in general features, so far as I understand them; and one, at least, failed to pass the Committee for the Selection of the Papers, either at the Norwich or Exeter Meeting of the British Association, on account of the entirely unpractical character of such a scheme. In the Papers submitted to this Institution, I think we should expect, unless we have a very careful and exact series of experiments, to have a very careful and exact statement of theory. Now, you will observe in the opening sentence of this Paper, we have this statement: "It may not be out "of place, in the first instance, to consider the size of waves which vessels may be required to encounter "under varying circumstances, and in different seas." In the first place I find no such consideration of sizes of waves that have to be met. In the next place, with regard to the invention itself, it is not, as I said before, a new one. It is a mere raft floating on three or four long cylinders. As to the connections exhibited in the diagrams, I cannot understand their being put forward as a mechanical contrivance, unless by some person who believed in the indefinite strength of a large number of rafts. It is all very well to say that if waves do not exceed more than half of the height of the cylinder, no serious damage will be inflicted upon that structure. That is a very singular statement to be made by a person who has ever seen the sea. It is quite true, as has been said, that "the sea is a very gentle beast, otherwise the tin "pots that are put upon it would never stand;" but it is very certain that, if we were to double our tin pots and convert them in this way, and put them upon it, they would not stick together for a moment. Then, with regard to the theoretical statements, we have it stated here that, as there is no aggregate forward motion of waves, so therefore there can be no retardation, provided the ship goes through the waves. If that argument is worth anything, it tends to contradict the other statement of the author, that there is a loss when the ship goes up, and again when it goes down the waves; because, when she goes down the waves, if there is any truth in Mr. Egerton's former statement, that should exactly counterbalance the retardation of the vessel when she is going up the waves. But we know perfectly well that the facts are not truly represented either in the one case or in the other. In point of fact the whole of the statements put together seem to me to be of that class which cannot possibly pass muster before an Institution of this kind. As a practical thing to be solved, no doubt there are tremendous difficulties in the way of bringing horses from Texas across the Atlantic with vessels of ordinary size; but if you would allow me to build a vessel 1,800 feet long—I will not say 420 feet beam, but I will join the two vessels together, and say 120 feet beam, and drawing 30 feet of water—I do not think I should find any difficulty in designing, and I think there are more than twenty persons here who would scarcely help being able to design, a vessel which would carry horses safely across the Atlantic. Therefore, I do not see, in the first place, what the object is that is proposed to be attained by this class of construction; and in the next place I do not see how it can be carried out. I am afraid that our Committee of Selection must have allowed this Paper to slip through rather unguardedly. I am sorry to make these remarks, but when a Paper of this kind is brought before a scientific Institution, it is necessary that the statements in it should not pass altogether unchallenged.

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Mr. Henry Liggins: When the author of this Paper alluded to the practicability of his new invention, as he termed it, being applied to the Channel service, it occurred to me I ought to say a few words, because for years past I have taken some interest in, and have read more than one Paper upon, this subject. When he tells us that the alteration in the general form of ships, for many years past, has undergone very little further change than that of adapting sailing vessels to steam vessels, I beg to remind him that upwards of twenty years ago I was on board during the trial trip of a steam boat, called the *Gemini*, on the River Thames. That was a re-copy of an exploded and proved failure of a bygone age. I advised a friend of mine, who was about to put £14,000 into that ship, to have nothing more to do with her; but he was an enthusiast, he went into it, and lost his £14,000. I lost the pleasure of coming back from Gravesend on the trial trip of that ship, because she was utterly incapable of any amount of speed; and yet the wiseacres of this day have not profited by that lesson, because they have built a ship again with two hulls, called the *Castalia;* and a more egregious failure as a ship than the *Castalia* there cannot be, unless it is, perhaps, the *Bessemer*. That ship has been built on the twin principle, with two hulls; and this gentleman has written a very long and nicely got up pamphlet, which I read some time ago, to illustrate that principle; but I am quite sure he is wrong in the statement, with which he begins his Paper, as to the form and size of waves, and the manner in which vessels of various sizes conduct themselves on certain waves. I should think that his experience of waves must have been obtained, probably, somewhere between London Bridge and the Nore, and not where mine has been, in the great Atlantic Ocean, where I find myself quite as safe in an open boat in a heavy gale of wind, if she is a good boat, as I have been in the finest of the Cunard steamers. The open boats of Deal and Ramsgate prove this. It is not the size of the ship that makes her safe, or adapted for a heavy sea; it is the form which is given to her, which is the result of ages of practice and genius: and the vessels that we have, of every size, are pretty well adapted for the safe transit of the English Channel. But if you want comfort for passengers, you must have that which we all know is essential, namely, size; and size, with other advantages, will necessarily give speed; speed gives satisfaction to the unaccustomed traveller on the water, and the voyage is rapidly got over. But when Mr. Egerton clearly tells us that a vessel will go faster through the waves than over the waves, he can have had no experience of that other novelty—which he seems to have forgotten—the cigar ship. Now, I have seen that most ridiculous thing, the cigar ship, under the trying circumstances of up-and-down motion, and pitching to a degree that was something frightful, and which made her the laughing-stock of everybody who was in my company at that time in an ordinary vessel, which was not pitching at all. That was simply off the Nore, with a strong North-east wind. The cigar ship could not go at all—she did nothing but play the see-saw on the top of the waves—and I think she frightened all on board of her. Therefore it is preposterous to say that such an arrangement as this is a suitable thing for bringing cattle over from Texas, or taking ladies to the Continent. Nothing of the kind is required. The Continental service is very easily adjusted and arrranged. It simply wants a good-sized, comfortable and roomy ship, of the type we have now, not drawing too much water, so that she may be able to utilise the ports on each side of the Channel. The author talks of Spithead being a port; but I should like to know how Spithead is to be a port for the unloading of this ship, 1,800 feet long? I think it was a pity, while he was about it, that he did not say 18,000 feet long, because that would have been as easily applicable; and it would have been as easy to obtain the money for the one as the other. In fact he might have gone to the extent of saying that he would make a bridge from Liverpool to Texas, for the cattle to march across; and I believe that

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would have been just as practicable and likely to be carried out as this very unconsidered scheme. Then he says, if this ship has paddle-wheels, she will turn in her own length. There is no novelty in that. I have been connected for the last forty years with the Southampton Docks. My father was the originator, and for upwards of twenty years the chairman, of that great work. I remember that the first tug, for bringing ships in and out, was made with paddle-wheels, which were disconnected, and I have seen that vessel do what peg-tops do—turn round on its own pivot. Therefore there is no novelty in a three-cylinder ship doing that. It would be a surprise to me if any vessel could not do that with disconnecting paddle-wheels on either side. This is not a subject that should be brought in this loose way before this scientific Institution, because it leads to no practical result.

The CHAIRMAN: As time is rushing rapidly forward, we will now go to the next Paper.

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ON PUMPING AND VENTILATING ARRANGEMENTS.*

By Thomas Morley, Esq., Member.

[Read at the Seventeenth Session of the Institution of Naval Architects, 6th April, 1876; John Scott Russell, Esq., F.R.S., Vice-President, in the Chair.]

I do not propose, and indeed it is impossible in the limits of this Paper, to do more than glance at a few considerations bearing upon the subjects of pumping and ventilating, and I have some little excuse for linking the two together, in the fact that some of the pumps I am about to speak of are capable of being used for ventilating purposes.

I wish to show that with comparatively little cost much greater pumping power can be given to ships than has hitherto been attempted in England, and to give some little idea of the thorough manner in which these matters are being dealt with in the Russian Navy under the very distinguished *régime* of Admiral Popoff.

I may perhaps be allowed to explain, therefore, that about this time last year I met Lieutenant Makaroff, of the Russian Navy, who has general charge of the pumping arrangements in all their ships, and I had the pleasure of showing him over the Imperial German iron-clads *Kaiser* and *Deutschland*, then building from the designs and under the inspection of Mr. E. J. Reed, C.B., M.P., by Messrs. Samuda Bros., of Poplar. While discussing the pumping arrangement of those ships Lieutenant Makaroff explained his own plans to me; and, at my request, he has recently sent me some sketches, and other information from Russia, and allowed me to refer to the matter in this Paper.

In order to meet or in some degree lessen the dangers of a collision, iron ships are divided into what are presumably water-tight compartments, and are fitted with pumps. It may be desirable in ships of war to increase the number of water-tight compartments, and depend rather upon them than upon the pumps; while in merchant ships, owing to the impracticability of cutting up the cargo space, it is, perhaps, necessary to depend

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chiefly upon the pumps; but, without expressing an opinion upon these matters, I may assume that in either case any increase of the pumping power is of the utmost value.

In the German ships before referred to, the pumping arrangements were very similar to those first fitted in the *Bellerophon*, and other ships of Mr. Reed's design, which were provided with inner bottoms, and every attention was paid to make them as complete as possible. As the general principles of these arrangements appear to have been followed in the Russian service, it may be convenient if I briefly enumerate them, and then indicate the departures from them which have been made in Russia.

An inner bottom is fitted amidships of sufficient length to include the engine, boiler, magazine and shell-room spaces. It is bounded at the fore and after ends by transverse water-tight bulkheads extending to the height of the main deck, and similar bulkheads are fitted so as to make separate water-tight compartments of the engine room, the after boiler room, the fore boiler room, and the magazine. Two other transverse water-tight bulkheads, extending to the main deck, are also fitted, one of them about 10 feet abaft the stem, and the other about 14 feet before the stern-post; they are termed the collision and stuffing box bulkheads respectively. Before and abaft the inner bottom the spaces are divided by horizontal water-tight flats, and the shaft passage is made water-tight. The space between the inner and outer bottoms is divided into several water-tight compartments, which are formed in a fore-and-aft direction by the vertical keel and a water-tight longitudinal frame at the turn of the bilge on either side; and in an athwartship direction by solid frames spaced about 20 feet apart.

Water-tight doors on the lower deck are fitted with hinges having loose pins, and are secured when shut by levers placed at short intervals all round the edges of the doors, which may be worked from either side of the bulkhead. The doors in the hold are made to slide up and down, being raised and lowered by a screw worked on the main deck. An objection has been made to such doors that they cannot be closed quickly enough, but a moment's reflection will show that the time taken in lowering the door depends upon the pitch of the screw, and if a pitch is chosen sufficiently coarse for the weight of the door just to overcome the friction, it will descend by its own weight almost instantaneously.

The pumps fitted are five 9-inch Downton's, placed on the lower deck, and capable of being worked either on the lower or main decks; two $5\frac{1}{2}$-inch Downton's placed on the main deck, and an auxiliary engine placed on the lower deck. This engine is supplied by steam either from a special auxiliary boiler, also on the lower deck, or from one of the main boilers. All the pumps are fitted for fire and wash-deck services, as well as

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for pumping from the bilge, and the auxiliary engine, in addition to serving for either of these purposes, can be applied to drive the foremost capstan.

The above-mentioned pumps being above the water-line, with a special boiler also above the water-line, may be worked long after water has risen sufficiently high to put out the fires in the main boilers. In addition to the foregoing, the two circulating pumps of the engine condensers, which are each fitted with 12-inch bilge suctions, and the donkey pumps, are capable of being used for discharging water from the bilge.

A main drain pipe, 12 inches in diameter, is placed between the two bottoms, extending for the whole length of the inner bottom, and is connected with each compartment of the ship by pipes fitted with valves of equal area to the section of the drain pipe. Valves of similar size are also fitted at the ends of the drain pipe to connect it with the compartments before and abaft the double bottom. The upper compartments of the double bottom are connected with the main drain pipe by 5-inch pipes fitted with valves at their upper ends. A reservoir is fitted at the lowest point of the drain pipe, and the suction from the auxiliary engine is connected at this place.

It will thus be seen that the main drain pipe has command of the water in every compartment of the ship except the compartments of the double bottom below the water-tight longitudinals. As no water is drained into these compartments it is expected that they will usually be quite dry, but in order to fill or empty them should they be used for carrying water ballast, or to pump from them in case of accident, stand pipes are placed in all the compartments. Each stand pipe is fitted with a valve so arranged that when screwed down it is wholly closed, when screwed half way down it acts as a non-return valve, and when the screw is up, the valve is kept open. Groups of two or more of these stand pipes are connected with each other and with a pipe leading from the nearest Downton's pump. By this means either of the compartments so grouped may be filled or emptied by the pump through this pipe. Each of the Downton's pumps has a sea suction through a Kingston valve, and suctions from the adjacent compartments of the hold inside of the inner bottom; and two of the pumps are connected with the drain pipe near the ends. This is done so that water may be let in for flushing, as the drain pipe is liable to get very dirty. Each compartment of the double bottom is fitted with a sounding tube extending to the main deck wherever practicable, and also with an air pipe led up between the frames to a height considerably above the water line. I may also mention that each compartment is fitted with two manholes, one of them being intended for access, and fitted with a cover easily removable, the other merely having a plate screwed on, and is intended to give ventilation when painting or other work is being done.

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Flooding arrangements are fitted to the magazines, shell rooms, and spirit rooms, proper stop-cocks, with locks, being fitted in each case to prevent the possibility of water being let in by mistake or by evil design.

As the stand-pipe valves control the lower compartments of the double bottom only, it is not necessary to have the means of working them when water has got beyond the inner bottom to the main compartments of the ship; but this is not the case with the other valves, and consequently they are all worked from the main deck, except in one or two instances, where it was impossible to get the necessary rods higher than the lower deck. Means are provided in every case for indicating whether the valve is open or shut. If the working of these valves is properly understood, water which enters the ship in any compartment may be conducted through the drain pipe to the pumps in any other compartment; but as the drain pipe is of the same size as the bilge suctions of each circulating pump of the engine condensers, *viz.*, 12 inches in diameter, it will only convey a sufficient quantity of water to the engine-room compartment to supply one of these pumps. In order, therefore, to render the second circulating pump available in case of accident to any other compartment than the engine room, 12-inch sluice valves are fitted in each bulkhead close down to the inner bottom—these valves, like the others, being worked from the main deck.

In ships of this class the pumping arrangements are necessarily complicated, and require not only the greatest vigilance in looking after such minor details as the proper marking of valves, the staying of rods, the insertion of brass bushes at pivoting points of levers, &c., &c., but also require on the part of those who have charge of the ship constant attention to keep every part in working order, and careful study so that in an emergency, at a moment's notice, they may know how to use the appliances with which the ship is fitted.

But to return to the Russian ships. The difficult navigation of the Baltic probably renders accidents somewhat frequent, and that may have something to do with the attention which Admiral Popoff gives to appliances for raising sunken vessels, for stopping leaks from the outside, and for increasing the pumping power in his ships. As instances of this I may refer to the Russian air-bags for raising ships, and Makaroff's mats for stopping leaks, both of which have been tried recently in England, and have attracted a considerable amount of attention. Lieutenant Makaroff, while devising means of pumping water out of the ships, has not forgotten that the most effectual way is to stop it from getting in; and his mats are so far appreciated in his own navy, that every ship has been supplied with them since 1870, and the seamen are regularly drilled in their use. They have been successful in saving at least two ships—in one case, the monitor

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Lava struck on a rock, and in the other the *Admiral Lazareff* was accidentally rammed by the *Admiral Spiridoff*. In both instances the mats were adjusted without difficulty, and the ships steamed safely into harbour.

The Russian pumping arrangements resemble those I have described for the German ships in having a main drain pipe of about 12 inches diameter, but it is differently arranged. Fig. 1 (Plate V.) shows the details of the valves: A and B are double-valve boxes capable of letting water into the drain pipe, either from above the inner bottom by the valves *c*, or from the double bottom by the valves *d;* E is a single-valve box which lets water in from the double bottom only at *f;* G is a sluice valve which divides the drain pipe into separate portions. By the lower valves D and F all the water in the double bottom may be pumped out except that which is within about 6 inches of the outside bottom. This water is pumped out by the pipes H, leading to a fore-and-aft pipe K in connection with the fire engine L. Downton's pumps are also connected with this pipe. The fire engine will also pump from the inner bottom by the pipes M. N is an ejector. Its connection with the drain pipe is shown in the section Fig. 2 (Plate V.) Fig. 2 also shows a centrifugal pump *a*, connected with the drain pipe at *b*, and discharging below the water line at *c*. The drain-pipe valves are made a little larger than the drain pipe; for instance, a 12-inch drain pipe would have 14-inch valves, as that is found to be an advantage. In the *Peter the Great* two centrifugal pumps and two ejectors are fitted, in addition to the fire-engine and Downton's pumps. One 12-inch pipe is found to be sufficient to supply both pumps and ejectors, as they are distributed along the length of the drain pipe, and the water will flow in either direction to them. An advantage of this arrangement of the drain pipe is, that should it be desirable upon going into action to sink the ship a little lower, water may be let in and the double bottom filled, by merely opening the valves; and if it is required to lighten the ship quickly, the whole may be pumped out in about ten minutes.

The centrifugal pumps are much more economical than the ejectors as regards the amount of steam used for the quantity of water pumped out. Each centrifugal pump has its own engine attached, and is supplied with steam from the main boilers.

On the other hand the ejectors are very light and inexpensive, and they occupy very little space. For these reasons it appears to me that they would be especially valuable in passenger steamers; for, in a case of dire extremity, the whole of the steam in the boilers would be available, and the ship might be kept afloat for a sufficient length of time, either for the passengers to escape in the boats, or for some means to be applied on the outside for stopping the leak. The *Admiral Popoff* is to be fitted with a Friedman's (Austrian) ejector, and a Morton's (English) ejector, with the intention of trying them

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against each other to see which is best. In these ejectors a pressure of 16 pounds of steam is sufficient to lift water 20 feet; 30 pounds will lift 40 feet; and 75 pounds 90 feet.

Although powerful centrifugal pumps and ejectors have been fitted in the Russian ships, it must not be forgotten that they depend upon the main boilers for steam, and consequently would be useless if the water rose sufficiently to put the fires out; but this point has not been neglected, and auxiliary engines and boilers have been fitted on the lower deck. In the *Peter the Great*, Merryweather's engine has been selected on account of its extremely light weight, and the rapidity with which it may be brought into action.

The quantity of water which may be thrown by centrifugal pumps and ejectors fitted in the manner shown, is enormous, as it depends upon the size and number fitted, the only limit being the quantity of steam which the main boilers will supply. Messrs. Stone of Deptford have just brought out a pump which is capable of throwing twice the quantity of water thrown by a Downton's pump of the same size; and although these bid fair to become most valuable as manual pumps, and should not be spoken lightly of, yet nothing that may be done in that direction can hope to compete with a combination of centrifugal pumps and ejectors such as I have described.

But Lieutenant Makaroff does not stop here: he proposes to fit centrifugal pumps, to be driven by gearing on the propeller shaft, as shown in Fig. 3 (Plate V.) By this arrangement he is confident that without disconnecting the screw a ton of water per minute could be thrown for every 8 indicated horse-power developed by the engine, and if the screw is disconnected a ton of water per minute for every 3 indicated horse-power; so that engines of 8,000 indicated horse-power, such as many armour-clads are fitted with, would be capable of throwing about 750 tons per minute without disconnecting the screw, or about 3,600 tons with the screw disconnected. Whether he will be able to find sufficient room for the pumps, and be allowed to carry out this idea, I cannot say.

Great facilities for pumping have recently been claimed as one of the advantages appertaining to circular ships. I have therefore shown, in Fig. 4 (Plate V.), the arrangements which have been introduced by Admiral Popoff in the ship which bears his name. The dotted lines represent water-tight divisions of the double bottom, and the drawn lines the main water-tight bulkheads. Pipes from the various compartments are led, as shown, to the inner circular bulkhead, within which three pumping engines are placed on a flat, raised as high above the keel as possible; the pumps are supplied with india-rubber hoses, long enough to reach either of the pipes, so that all three pumps may be applied to any one compartment of the ship.

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An important advantage of the centrifugal pumps is that they are capable of driving air as well as water; and they may, if desired, be used for ventilating any compartment of the ship, the necessary pipes, of course, being provided. In many ships it is difficult to get sufficient draught in the stoke-hole without artificial appliances; in some of the monitors special fans have been required for ventilating the cabins, mess decks, &c.; and in emigrant ships especially good ventilation is needed. In all of these cases centrifugal pumps would be capable of serving a double purpose.

This leads me to the second part of my subject, *viz.*, ventilation, and I would urge the importance of it, not solely on the grounds of health and comfort, but because explosive gases are generated by some descriptions of cargo, such for instance as coal, and many serious accidents have occurred through the neglect of proper ventilation.

The frame spaces of iron ships and the hollow iron masts form excellent ventilating pipes. The masts especially are good uptakes, and should always be fitted with open covers at the masthead, and with perforations at the heels, so as to allow foul air to pass up.

I may here observe that in arranging uptakes the greatest care should be taken to convey the foul air away to the upper deck by distinct pipes from the hold and from each deck; for, if this is not done, there is a liability of the living deck becoming contaminated by the gases from below.

Another observation I wish to make is—and this is a point which, as far as my experience goes, has received very little attention—that means should be provided for closing all ventilators in case of fire. This is especially important in the case of the iron masts, for if a fire breaks out in the hold, in the vicinity of an iron mast, the mast at once becomes a tall chimney, and will create an enormous draught to fan the flames. The *Times*, of the 21st January last, contains an instance of this. Under the heading "A Perilous Voyage," it gives an account of a fire on board the *River Boyne*, Captain Rice, bound for Valparaiso with a cargo of coals. When near Cape Horn it was found that the coal had taken fire, and most praiseworthy exertions appear to have been made to put the fire out, but without success. Fortunately they were near the land, and found a snug little harbour, in which Captain Rice ran his ship on shore and scuttled her. The flames were thus quenched, the water was then pumped out, and he ship went on her voyage again. In Captain Rice's letter to his owners, an extract of which was given in the *Times*, the following paragraph occurs:—"Anchored in six "fathoms, stiff sandy bottom, *the smoke by this time coming out strong from under the caps* "*of the fore and mainmasts.*" It is obvious that the masts in this case must have created a draught, which materially increased the fire; and further, if these masts had

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been fitted with valves by which the upward current of air could have been stopped, or if the captain had caused the mastheads to be covered over, the probability is that he would have put the fire out without having to scuttle his ship.

In view, therefore, of the serious consequences arising from a fire at sea, I venture to suggest to shipowners, surveyors, and underwriters, that the propriety of enforcing some means for closing all ventilators, and especially iron masts when used as such, is a question worthy of their most serious attention.

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ON THE PRESENT SYSTEM OF SEACOCKS AND THEIR CONNECTIONS IN STEAMERS.*

By H. G. Spence, Esq., Member.

[Read at the Seventeenth Session of the Institution of Naval Architects, 6th April, 1876; John Scott Russell, Esq., F.R.S., Vice-President, in the Chair.]

In the present agitation with regard to unseaworthy ships, I wish to call your attention to a danger in every steamer which has been entirely overlooked in any of the discussions that have taken place on this now all-important subject; and which is of far greater importance than any of the dangers Government has been called upon to legislate against—a danger which every engineer is well aware of, and of which the evidence we have from Board of Trade enquiries, the reports in the *Shipping Gazette*, and from other sources, clearly shows that some improvement is required in the present system of the sea connections in a steamer to make her perfectly seaworthy. For however well a vessel may be constructed, if all the iron be tested and care taken that she be not overloaded, she still may be lost in the way, I daresay, many of the silent losses have occurred—and that is through the hidden dangers of the engine room; for there, with the greatest care, accidents have happened, not only in the ordinary cargo steamer, but even in the large American liners, and in vessels in whose construction no money has been spared—Her Majesty's ironclads; an accident which has sent many a fine vessel with her valuable crew to the bottom, and for the prevention of which I wish now to call your attention.

In the engine room of a steamer, as you will all be aware, there are at present cut through the bottom or bilge of the vessel's shell five or six holes for the purpose of admitting or discharging the necessary water for the proper working of the engines and boilers; these holes are covered by what are technically known as seacocks, which are bolted on to the skin or shell of the vessel, the larger ones being generally of cast-iron, and the smaller of brass; these are connected to the engines and boilers by pipes of lead

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or copper, which are generally placed low down on the vessel's floor so as to be out of the way. The engine-room platform, as well as the stoke-hole plates, being a considerable height above these pipes, in some cases as much as three or four feet.

One of the dangers, therefore, consists in the position of these seacocks and pipes; for, necessarily being very low down on the bilge, or in the bottom, they are under the engine-room platform and out of sight, so that should a leak occur in a cock or pipe it is not found out till the water coming over the stoke-hole floor warns the engineer or fireman that something is wrong; but it is then too late, for the engineer cannot see what is the cause of the leak, everthing being covered with water, and unless the pumps are capable of overcoming this leak, the vessel ultimately founders.

On this point I will give you the following extract from the evidence given before the Royal Commission on Unseaworthy Ships, by Mr. Waymouth, Secretary to Lloyd's Registry, on the loss of the *Knight Templar*:—

"8,126. (*Mr. Brassey*) Assuming that this leakage did occur through some pipes "connected with the engine, do you not think that the leakage in those pipes was "probably occasioned by a strain upon the vessel from the structure of the vessel "having yielded to the force of the sea?—If the information I have received is correct, "I do not imagine it was in consequence of the pipes giving way, but in consequence of "water being let into the ship by the pipes or valves being arranged in the way they "were, not from anything yielding or giving way. I know in the case of one ship, "which was lying in dock quite recently, five cocks had to be opened before one could "let water into the ship, and yet there was found to be 6 feet of water in the hold, and "the cargo was damaged, but the ship proved perfectly water-tight. I have known "many cases where vessels have had a serious amount of water let into them. In one "case in particular, a vessel put into Falmouth, which was considered to be very leaky, "and engineers were sent down from London to see what was the matter with her, but "the ship became tight of her own accord, without anything being done to her."

"8,127. (*Chairman.*) What had been the cause of the leakage in that case?— "Something wrong in the engine room; they had let the water into the ship with the "cocks, and I believe many a ship goes to the bottom in consequence of the water being "let into the ship in that way."

Mr. E. J. Reed, M.P., also said, in reply to the question asked by Mr. Denny:—

"9,521. (*Mr. Denny.*) With regard to the loss of ships at sea: sometimes ships are "lost and never heard of; may not those losses occur from the straining of the ship, "causing a breakage of the seacocks, and the water coming in?—I think that very often

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" happens. I think probably many of the silent losses occur from the breaking of the " pipes in connection with the bottom from the straining of the ship."

We have also the case of the French Transatlantic steamer, *Europe*, of 4,000 tons, abandoned in the Atlantic on April 2nd, 1874, the crew and passengers, in all about four hundred persons, being taken off the sinking vessel by the English steamer, *Greece*, the officers of which vessel held a survey on the *Europe*, finding about 6 feet of water in the engine room and stoke-hole, and only 1 foot in the adjoining holds. A prize crew was put on board and they tried for several days to pump the water out, but bad weather coming on, they signalled the steamer *Egypt;* after which they tried to tow her into some port, but at last had to abandon her with 18 feet of water in the engine room, only 8 feet in the main, and 3 feet in the after-hold, and for several days afterwards this vessel was reported as knocking about in the Atlantic.

It is therefore evident the leak was in the engine room, and from some sea connections, which is proved by a very singular and strange coincidence, for a few days after her sister ship, *Amérique*, of 4,000 tons, and belonging to the same owners, was abandoned in the English Channel, afterwards picked up and towed into Plymouth, with the engine room full of water. When it was pumped out nothing was found wrong with the vessel, she was towed to Havre and put into dry dock; the hull was found perfect, and what had gone wrong with the sea connections was never made public. The value of these two ships would be about £150,000; and had just been rebuilt and new engined by two first-class English firms.

The *Ormesby*, of 930 tons and 140 horse power, was abandoned January, 1874, in the Bay of Biscay. From a Board of Trade inquiry into her loss, we find, that after the vessel had encountered a heavy gale, and when it was comparatively calm, water was suddenly discovered coming into the engine room and stoke-hole, which in a short time lifted the stoke-hole plates and put the fires out. The carpenter sounded the ballast tanks (one being under the engines and boilers), main and after holds, and found no water in them. A fireman stated the leak was not in the coal bunkers, as the coals were quite dry till the water was over the stoke-hole plates, so that the leak was traced to the space between the tank side and the bottom of the coal bunker, or in the neighbourhood of the seacocks, and the assessors, in making their report, stated:—" But whether it arose from " the starting of a plate, or from any accident or straining in the locality of the seacock " (which was an ordinary stop valve, the casing of cast iron, and the only seacock that " was submerged when the leak was discovered), there was no evidence to show."

Now considering this case from a shipbuilder's point of view, the water must have come from some sea connection; for if the vessel had strained, or started a plate, it

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would have shown itself in the gale she encountered, not in a comparatively calm sea. and would also have shown water in the ballast tanks, the main hold, or in her topsides, and not in her bilge, which, from the vessel's construction, owing to the tank side, was the strongest part of the ship.

The exposed position of these seacocks is very dangerous, being liable to get broken off, and the pipes lying on the floors of the vessel to get chafed or broken in two, by the constant working of the ship.

Let us suppose a steamer with water, from some cause or another, in the engine room, perhaps with the engines broken down, owing to the shaft breaking or any other cause, and the fires drowned out. As the vessel rolls, the water rushes from side to side, lifts a stoke-hole plate, fire bar, a lump of coal or anything else, and dashing it against a seacock, off it comes, or damages a pipe, for in the present system there is nothing to prevent it. It may cause only a small hole, but it is no easy matter to plug it, when you have not only a heavy pressure of water against you outside, but when the engineer also has to work with his hand and arm in water.

The arrangement of having seacocks with three-way turns, or openings, has also led to several mishaps, for these three-way cocks are very difficult to make, and if perfect when new, soon wear the openings into a very dangerous state; the object of these three-way openings being that the engineer can so regulate them by turning the handle, to pump either from the sea, or bilge water in the ship. However, sometimes the engineer turns the handle the wrong way, the cock is not properly constructed, or is wrongly marked, the consequence being, water instead of going into the engines, goes into the ship; this being most likely the cause, assisted afterwards by the breaking of the ashcock pipe, of the foundering of the *La Plata*, with her crew of seventy hands; the assessors saying in their report, "We are of opinion, that somewhere about 8 a.m., one or more of the cocks in the engine room, must have been set incorrectly, as we cannot in any other way, account for the steady increase of the water after that time, as we know from the evidence that one or more of the cocks were then moved."

I have myself known this to occur in new steamers after the first turn round of the engines, the water to accumulate to a frightful extent; and it was this happening a few years back, that called my attention to this serious source of danger and to scheme out some plan of preventing it.

It is well known to every one connected with steamers that water often gets into the engine room, and from here into the holds, damaging a lot of cargo, while the vessel is quietly in dock, from some unknown cause, and then as suddenly stopping; the

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stopping being caused by the engineer trying his seacocks again and getting the plug into the right position. A case of this sort was brought to my notice in January, 1874. The *Rosa*, of Hartlepool, when loaded with iron in the Tees, was found making a great quantity of water; the leak was so great it was thought the bottom was nearly out of her; the cargo was discharged and she was taken into dry dock, when, to the astonishment of every one, not a defect was to be seen in the hull, and the cause of the leak not found out. The ship was undocked, took in her cargo again, and went to sea. Another steamer, lying alongside a quay, was also found leaking badly, and it was decided to put her on the slip; the owner, however, telling the engineers if the hull was found all right they would have to pay all expenses,—the leak stopped, and the engineer acknowledged that one of the seacocks was wrong, so the vessel went to sea without the expense of slipping.

No doubt many of you will remember the case of a London steamer, the *Uitenhage*, some eight years back, which was bound for the Cape with passengers, but after leaving Falmouth forty-eight hours came back with 5 or 6 feet of water in the engine room. In harbour she became tight, went to sea again, but returned after a lapse of the same period, was again pumped out and went to sea once more, but after four or five days reappeared in the Thames with the engine room flooded. She again became tight in harbour, the cargo was discharged, and vessel went into dry dock. When the dock was empty the ship was filled with water to the height of 10 feet; the hull was found perfectly tight, and nothing further discovered. She then proceeded on her voyage without anything being made public as to the cause, leaving a strong suspicion that some cock had been wrong, as, doubtless, must have been the case.

Numerous instances of this kind could be brought forward, but to show this is no uncommon accident, and is still going on, I must call your attention to a paragraph in the *Maritime Registry* of May 14th, 1875:—

"*King Arthur* at Bombay having finished loading cotton, was discovered to be "leaking badly, and was obliged to be beached. Cargo would have to be discharged "to get at the damage."

In the *Registry* of June 11th we find—

"The surveyors appointed to report on the leak of the *King Arthur* at Bombay "were unable to find any cause for it, and were of opinion that the sudden leak "must have arisen in some way in the engine room. She has to go out of dock and "reload her cargo."

Here you see cases of ships leaking at sea and in harbour. What is to prevent this occurring again? Nothing. And doubtless vessels have been lost (when the engines

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have been broken down), from water getting into them at sea, in the same way as in harbour, and with no help at hand to save them.

When a great amount of water gets into an engine-room, to pump it out quicker it is a common practice to fit a bilge injection on to the inlet-pipe of the circulating pump, but the "cure is sometimes worse than the disease," and has proved another cause of danger—as shown by the loss of the *Knight Templar*. This was a new ship, classed at Lloyd's, and with a Board of Trade certificate, and when only some sixty hours from port she foundered. At the time it was thought the vessel was lost through straining, but it was found out afterwards—through the engines of a sister ship—that a bilge injection so fitted admitted water into the ship from the sea.

Since this has been found out, non-return valves have to be fitted, but this is not sufficient, as the valve may not act through coal dust or a chip of wood getting into it. This accident, I fancy, had something to do with the loss of the *Europe* and *Amérique*, and was possibly the cause of the water getting into Her Majesty's ironclad, the *Iron Duke*.

To show I have not exaggerated the liability of vessels to be lost through the present system, I will give you a few extracts out of several I have copied from the *Shipping Gazette* of 1873, 1874, 1875:—

" *Francesco Calderon* foundered on January 19th, 1873, having sprung a leak, caused " by the giving way or breakage of some of the pipes connected with the skin plating " from the boilers or engines." (This extract is from the Royal Commission on Unseaworthy Ships.) " *Sunfoo* put into Malta, April 16th, 1873, very leaky, was placed in " dry dock, and the leak was found to have been caused by a Kingston valve being " broken and destroyed." " *Aberford* left Gibraltar at five o'clock on June 26th, 1873, " put back two hours afterwards with stoke-hole full of water, one of her sea pipes " having burst." " *Captain Cook*, of Whitby, abandoned at sea, picked up and taken to " Grimsby, engine room full of water, caused by one of the seacock glands giving way." " *Andes*, while lying at anchor in the Harbour of Naples on September 5th, 1873, was " found to have 5 feet of water in engine room and 4 feet in after-hold: with the aid of " three powerful pumps the water was reduced to 3 feet in engine room and after-hold " cleared; it was then discovered that the bolts of the flange of donkey engine feed-" pipe had given way." " *Brunette* was nearly sunk in the Thames by a fireman " wilfully opening a cock in the night; the vessel had to be beached, and the steam " floating fire engines had to pump her out before the engineer could reach the cock " to close it." " *Talisman* foundered in the Bay of Biscay with the loss of twelve men; " the engineer, one evening, found the water coming into the stoke-hole with a rush, in a

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" short time there was 13 feet of water and she went down." " *Thibet*, mail steamer, " sailed from Malta for Port Said, April 4th, 1875, but put back; she was surveyed and " examined by dockyard divers, and found perfectly tight and seaworthy; she sailed " again for Port Said in the evening." " *Orlando*, at Hull from Gothenburg, whilst " discharging, February 17th, 1876, several feet of water found in her, supposed that " the stop-cock was left open; large quantities of cargo damaged."

These few cases clearly show that engine room connections require improvement.

We may consider the engineering talent of the Royal Navy to be of the very highest class; and yet we find, with all their skill and precaution, accidents have happened in separate dockyards which have been made public. In the *Standard* of last August appeared this paragraph, from Chatham:—" Great anxiety has been felt about the safety " of the iron-clad frigate *Rover*, now preparing for sea, in consequence of one of the sea- " cocks having inadvertently been left open, which caused the water to commence " running into the ship." And we all remember the commotion created the end of last year by the news of another of our iron-clads being in danger, the *Iron Duke* being reported sinking at Plymouth, through water getting into the ship in some mysterious manner.

Lloyd's now require all cocks fitted on the plating of steam vessels to be raised above the level of the stoke-hole plates, on the turn of the bilge, or attached to Kingston valves of sufficient height to lift them up to the level of the stoke-hole plates, so that they can at all times be seen and attended to. By this rule Lloyd's are coming back to the old plan of having the seacocks high on the bilge, which is all right in its way, but has this disadvantage, that when the vessel is light the engines may be useless by the seacocks getting out of the water. Suppose a steamer of 1,000 tons, having ballast tanks, one being in the engine room, the stoke-hole plates would be about 6 feet 2 inches above the bottom of keel; the seacock above this will make it about 6 feet 7 inches, and as the vessel will only draw about 9 feet 7 inches, it leaves but 3 feet from the seacock to the water-line; so that if the vessel takes a list, or rolls about a good deal, the injection valve is out of water.

I remember, some fifteen years back, the steamer *Frankfort*, bound for Liverpool with a cargo of cattle, getting on her beam ends through the sand ballast shifting, having to run before the wind into Belfast Lough; the ballast was there put to rights, and she steamed back to Liverpool. But suppose the wind had not been favourable, she might have got on a lee shore and been lost.

If the Kingston valves are made higher than at present they are all the more liable to get broken off, for the bottom of them will still be under the stoke-hole floors.

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Having now shown you that vessels, not only of the Royal Navy, but others built and engined in different yards, and under the surveys of Lloyd's, the Liverpool Registry, and Board of Trade, have all proved defective, I make bold to bring before you a plan I have designed as a complete remedy against the danger alluded to, and which has been adopted with complete success in the steamer *Helios*, of Hull, for nearly three years, and is also fitted on the *Stelvio*, and *Monte Moro*, of Shields; and the *J. B. Eminson*, of Sunderland.

The plan is a simple one, being analogous to a gas meter, by which we have the means of shutting off the gas from the various pipes; and in my arrangement I place a valve in an iron box, by which the water can be shut off from the various seacocks and connections.

You will observe from the diagrams (Plate VI.), that on the bilge of the vessel, a large valve is placed, the area of sea opening of which is equal to the area of all the other seacocks, and this valve, which is a Kingston one, is opened and shut from the deck. Over this valve an iron box is built of the same strength as the ship, which is made perfectly water-tight, and on the outside of this box are placed the circulating, ballast, ash—and in fact all cocks. You will see therefore, that water getting to the various cocks depends upon the main valve being open or shut; and this valve being enclosed in the box, cannot by any means get broken; and when shut, the shell of the vessel is as perfect as if there were no hole.

For the boiler, blow-off, and scum cocks, there is another box with a Kingston valve inside, which also opens and shuts from the deck.

The advantages I claim for this arrangement are as follows:—

1.—That by shutting the main valves from the deck, no more water can get into the ship; and the ship is perfectly tight, so far as seacocks are concerned.

2.—In case of a breakdown, the main valve is shut—when the officers and crew are certain no water can enter the vessel through that source.

3.—All the cocks are placed at the top of the box, above the engine-room platform, and always in sight.

4.—If anything should go wrong with the main valve, you have always the outside cocks to depend upon—and which, moreover, are always in view.

5.—Any doubt existing as to the source of leakage, the main valve is closed; the result being seen if the leak is from a pipe, or from the shell of the vessel.

6.—The main valve is easily shut in dock, thus preventing any cargo getting damaged.

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7.—If necessary the handle of the valve can be locked when in dock, to prevent people tampering with any cock.

8.—The facility of repairing any seacock or pipe, at sea or in harbour without going into dry dock.

In making the box, care is requisite to make it quite tight; and a plan I have adopted to test this is, to take a small pipe from the box to the deck, and fill it with water to the top, before the vessel is launched. If the box is then tight, it will never leak afterwards. Some builders build the box on to the ship's frame, but it is better to cut a frame which can be compensated for, and putting a welded angle iron right round the box, which is then easily caulked all round.

The main valve being a Kingston one, some engineer may say, if the valve is shut in dock, it will be very difficult to open, with a pressure of say 16 feet or 18 feet outside. This can be obviated by taking a small $\frac{1}{2}$-inch gas-pipe from the ship's side with a small pet-cock to the top of the box; but in practice, I have not found this to be required.

The large drawing is of this arrangement as fitted on the steamer *Helios*, of Hull, with engines of 140 horse-power, by C. D. Holmes & Co., of Hull. This vessel has now been built for nearly three years, and has proved a great success.

Fig. 1 (Plate VII.) shows the valve as fitted on the *J. B. Eminson*, of 100 horse-power engines by T. Richardson & Sons, of Hartlepool. Fig. 2, a proposed plan for blow-off cocks. Figs. 3 & 4, the handle and arrangement for working the main valves from the deck. This handle is worked by simply unscrewing the brass cover off the top of box, and turning the handle round, when it slips down the opening, and the valve is shut.

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DISCUSSION ON THE TWO PRECEDING PAPERS.

Mr. JAMES WRIGHT: There are two or three statements in Mr. Spence's Paper which I should like to call attention to, because they are not quite correct. He refers to fittings and seacocks in ships of war being the same as those in merchant vessels, and he says, "These holes" (that is the openings through the skin of the ship) "are covered by what are generally known as seacocks, which are bolted on to "the skin or shell of the vessel, the larger ones being generally of cast iron, and the smaller of brass." Now, for more than thirty years in the Navy every pipe going through the bottom of a ship connected with the sea has been fitted with a Kingston valve, and on that valve a stop-cock has been fitted, if it were a small one, or a sluice valve if it were a large one. These valves have always been made of brass. Then in addition to that all pipes going to the bilge, that is to say the suction pipes of all pumps, have been for many years fitted with self-acting non-return valves. Mr. Spence says, "Having "shown you that vessels not only of the Royal Navy, but others built and engined in different yards, and "under the surveys of Lloyd's, the Liverpool Registry, and Board of Trade, have all proved defective," and then he goes on to propose his own plan. He leaves it to be inferred by the way this sentence is worded that all those of the Royal Navy have been considerably more defective than any others. Now, I maintain that the Royal Navy has been peculiarly free from accidents arising from seacocks; and I ask any engineer whether, if for more than thirty years we have had ships fitted with seacocks such as I have mentioned, it is likely that such accidents could often take place. Mr. Spence illustrates his case by referring to the *Iron Duke* and the *Rover*. The *Rover's* case was simply this. After the men had left the yard, a policeman was going his round, and he went down to the screw alley, and heard a trickling of water there. He then went and gave the alarm that water was running into the ship. That circumstance, of course, caused considerable commotion in the yard, and I suppose at the gate; and the circumstances passed, no doubt, from mouth to mouth, and by the time it got to the reporter it was described thus: "Great anxiety has been felt about the safety of the iron-clad frigate *Rover*, "now preparing for sea, in consequence of one of the seacocks having inadvertently been left open, "which caused the water to commence running into the ship." Now, the fact was simply this. The contractor's work-people were engaged upon the engines, and it was necessary that they should turn the engines round by hand, and to make that operation rather easier, they slacked back the gland of the stern-shaft stuffing box, so much so, that a little water kept trickling down from the stuffing box. That was what the policeman heard; and, very properly for a policeman, he gave warning of what he did hear. The case of the *Iron Duke*, also to which the author of the Paper has referred as proving that in the Royal Navy these disasters have occurred, is a rather different case, and, I grant him, one of more importance. The explanation of that is this:—The large Kingston valve for the inlet pipe of the circulating pump has on it a sluice valve, as all large Kingston valves have. Some alterations were made in the hand gear for working the sluice valve, to bring it more within the range of the engineer when he stands on the platform. The fitter who did this work, and marked the index "open" and "shut," most unfortunately marked it "shut" where it should have been "open," and "open" where it should have been "shut." The *Iron Duke* was going out for a short run, and most of the engineers being new to the ship, it was thought the sluice valve was opened; but when they got a little way out, they found that the condenser was getting warm. They then turned on the sea injection

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to cool down the condenser, without thinking where the sea injection water was to go to. When the *Iron Duke's* condenser is worked as a common condenser, a valve should be opened to allow the discharge to go overboard, but they omitted to do this, and the surplus water got into the feed tanks which supply the feed pumps. This extra amount of water pumped into these feed tanks, situated in the passage between the engine room and boilers, overflowed into the bilge. The whole amount of the water that passed in was very little, and the steam pump cleared it out in ten minutes. As soon as the engineers found that the water was warm, they knew it was coming through the engine; they stopped the sea injection, and soon got things put right. I think, with reference to these cases—and I do not think that Mr. Spence is prepared to give us more disasters from seacocks in the Navy—his statements are, to say the least, rather exaggerated. His plan may do very well in a small ship, where you can get the chamber close to the skin of the ship; but all our big ships have double bottoms and wing passages or coal-box bulkheads along the sides, and it would not be easy to get in such a chamber as that; and, moreover, the type of engine is different in many cases; and it is not always easy to bring all the seacocks to one box. In large ships, such as first-class iron-clads, we require for the surface condensers alone two inlet pipes, each 20 inches in diameter, and I think he would be a bold man who would bring all those under one Kingston valve. The plan adopted in the Navy with the Kingston valve and the checkcock contains all the advantages which Mr. Spence claims for his plan, except, of course, that there are more of them; and if there are more of them, he may say there is more liability to derangement. But it may not be out of place to remind the Meeting, looking at Mr. Spence's plan, as applied especially to large vessels of war, that it is not wise to put all your eggs into one basket.

Mr. PARKER: No doubt a number of accidents have occurred, and a number of vessels have been lost by faulty arrangements of cocks and pipes in the engine room; but I fail to see how Mr. Spence's suggestion can remedy this evil. Silent dangers in the engine room do not, in my opinion, generally arise from the seacocks, but from the intermediate pipes and cocks that connect the pumps and engines with the sea and bilge suction. This subject was brought before the Committee of Lloyd's Register about eighteen months ago, and they caused a number of steamers, forty-five in all, to be examined. Twenty of them had the means of running the water direct from the sea into the bilge by the engineer accidentally turning a cock in the wrong direction. In consequence of this, Lloyd's Committee requested their engineers' surveyors to examine all cocks and pipes in steamers coming under survey; and they now trace every pipe, and examine every cock, and satisfy themselves that no such arrangement can exist before they report vessels to the Committee for the renewal of their class. Seacocks are, to a certain extent, sources of danger, especially when fitted upon the flat of the vessel's floor, 3 feet or 4 feet beneath the stoke-hole plates, some of them are subject to sudden shocks when the boiler is being blown off; the glands may leak or the joints may be started, and when in this position they cannot be seen—being almost always covered with water. Lloyd's Rules now insist upon these cocks being fitted above the stoke-hole plates, so that they can be always seen and attended to; and the spanners of these cocks are so fitted that they cannot be taken off unless the cocks are shut. The engineers can now see at a glance whether the cock is open or shut. I think that little more can be done in this direction to diminish these dangers.

Mr. C. W. MERRIFIELD, F.R.S.: I should like to say a few words upon this subject. While admitting the great difficulty of applying any process of the nature of Mr. Spence's invention to ships of war where the engines are especially large, and also without venturing to express an opinion

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as to whether Mr. Spence's solution of the difficulty, is really a full solution of the difficulty, or still less, whether it is a good or bad solution, I think it is a step in the right direction. I think no person can have seen a large number of merchant vessels in our dry docks, as I have, without noticing that there are, to say the least, a great number of holes in the bottom of the ship. Five or six have been mentioned. I have counted as many as eleven; and I am not quite sure whether that is the maximum. Those in the case of a merchant ship are not all large holes of 20 inches diameter; and I quite agree with Mr. Wright that there may be some difficulty in bringing such openings as these into one trunk; but as to merchant ships, taking into consideration what one actually sees in the bottom, that is to say, on an average eight to ten moderate-sized holes, as large as, or perhaps a little larger than the bottom of the inkstand on the table, more or less guarded with perforated zinc, I think one must admit, knowing what sort of sea connections are usually put into them, that there is the chance of their getting wrong, and of there being something irregular about the lead of the valves. With regard to the case of the *La Plata*, I heard all the evidence myself, and watched it very closely; but in that, as in many other cases in which I have simply read the evidence, it was impossible to get at the facts. There were suspicions that the valves were wrong, and that the engineer did not understand them, and every description of suspicion; but there was no evidence of what was really the matter. I must say I think there can be no real difficulty in paying a little more attention to these matters than we ever find actually done; and that we should endeavour, at all events, to diminish the number of holes at the bottom of the ship, which are beyond the control of everybody but the engineer, and not apparently under his efficient control. If I was the captain of a vessel, when anything was going wrong in the engine room, instead of hanging the engineer, or battening him down, if I did not find out what was the matter, I should like to be able to say to him, "Look here! the ship is sinking, I am not going to stand any nonsense, I will "shut up all your sluice holes, and you must get your water from somewhere else, but the ship shall not "go down." Whether Mr. Spence has given the best, or has given a complete solution, is another question, but I myself rather doubt Mr. Spence's solution, because I see sundry difficulties which are not provided for. All sorts of things could get into his valves. It may sound very ridicnlous; but not only sand, mud, and seaweed from the harbours, but all sorts of living things, such as fish, that will grow there, and blubber, that may accumulate in enormous quantities, may stop the injection, and make all sorts of messes in the ship. Without saying that he has solved the problem, I am quite sure it is a problem to be solved, and Mr. Spence has done very good work in calling our attention seriously to it.

Mr. B. MARTELL: I have listened with much pleasure to the Paper which was read by Mr. Morley, because it showed that a great amount of attention is being given to the safety of our ships of war. Taking these pumping arrangements in connection with the large number of compartments referred to this morning, they show a greater amount of safety in the Government ships than persons generally give them credit for. I was likewise pleased at the same time to hear Mr. Morley say that he did not refer to the merchant ships as requiring these elaborate arrangements, because being for ordinary mercantile purposes it could not be expected that they could be fitted with bulkheads such as are necessary in the war ships to which he alluded. I thought this morning my friend Mr. Barnes had rather prepared himself to meet Mr. Boold's Paper with the old argument, "You are another." He appeared in effect to say to him, "You are finding fault with the Royal Navy authorities, but take care of your merchant ships, and we will take care of our war ships." It should be borne in mind that a ship designed for mercantile purposes is essentially different from a ship designed for purposes

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of war. Mr. Boolds wished simply to point out that the various bulkheads in war ships could be utilized for purposes of safety, and that seeing the cargo or rather the weights are always the same in them, it is known precisely what is to go into the ship; and that in a Government ship these bulkheads could be arranged in such a manner as to form effective water-tight compartments; but when Mr. Barnes says, "Why don't you fit these to your merchant ships in the same way?" the observation is out of place. Mr. Barnes alluded to what the Council of this Society recommended some time ago with reference to the fitting of a larger number of bulkheads in merchant ships; but, if I remember rightly, the Council also at the same time recommended how ships were to be loaded, and what freeboard they were to have; and I fancy that, perhaps, the reason why merchants did not follow their rule for bulkheads was the same as that which they had for not following the rule for loading ships, and as to the draught of water applicable to merchant ships. If I am rightly informed there has been a Committee of this Institution recently appointed, who have drawn up Resolutions as to merchant ships at the present time with reference to the Bill that is now before Parliament, and that certain Resolutions were decided upon by them, and presented to the Government; and I certainly had hoped to have heard some of those Resolutions at this Meeting, because I think, seeing that the previous Resolutions in regard to freeboard and bulkheads were perfectly inapplicable to the mercantile marine of this country and were not adopted, it is highly probable that the Resolutions now passed are likewise not applicable, and would not commend themselves to the common sense of the mercantile world. This shows the great importance of bringing such matters before the General Meeting, so that such Resolutions should be considered by persons engaged in mercantile pursuits, connected with mercantile ships, and perfectly understanding all the requirements of the mercantile marine, before they are put forward in the name of this great Institution. I merely wished to make these remarks because I thought Mr. Barnes was rather unfair to Mr. Boolds, and one might have supposed from his remarks that when Mr. Boolds found fault with the Government, he did it in a captious spirit; but I know him so well that I can say it was not done with that intent, but for the public good. As regards fitting bulkheads to merchant ships in a similar manner to those which are required in Government ships, that would compel an owner to cut a ship into small compartments, and thus render her incapable of complying with the demands for which she was built. Therefore to make a rule of that kind is perfectly absurd, because it is impracticable. With regard to Mr. Spence's plan, something no doubt can be done, as Mr. Merrifield has said, to afford greater protection than has been afforded hitherto to these inlets, because we know from our own experience that in numerous cases serious accidents have happened, and ships have been lost, which may be attributed to the carelessness of engineers, and want of knowledge with regard to these seacocks, and, therefore, any such proposition for affording additional security in this respect demands the greatest attention from engineers.

Mr. J. Fortescue Flannery: I think the explanation which Mr. Wright has given is quite sufficient to show that the *Rover* and the *Iron Duke* are quite removed from the category that Mr. Spence has mentioned. I venture upon this opinion with all deference to Mr. Parker, who said that a very great and serious danger exists with the present means of fitting ships with only a single skin. I do not think that vessels with double skins were intended by Mr. Spence. To my mind the greatest source of danger lies in the fact that these cocks are entirely out of sight, at least they are very much below the sight of the engineer in his ordinary daily duties; and they may, in case of danger from a leak, be entirely submerged, and entirely out of reach of remedy before the defect is discovered. Mr. Spence has multiplied instances of ships that in his opinion, and that of many eminent authorities (Mr. Reed among

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the number), have sunk from these causes; and if it were at all necessary, although I do not think it is, I believe I could quote from my own recollection more than one ship—indeed there are two I remember—which sank in the dock entirely from this cause, as was found upon pumping out and upon examination. You, Sir, will correct me if I am wrong; but I think the *Great Eastern* at one time sustained damage to her outer skin, and steamed for many miles with the protection afforded by the inner skin. It appears to me that Mr. Spence's aim is entirely in the same direction as that of the constructor of the *Great Eastern* and other ships—that of having a double bottom. He wishes to put a double bottom between the sea and the inside of the ship, so far as the seacocks are concerned, and there is no doubt that double bottoms will more than doubly increase the safety of the vessel. I should like also to allude to one paragraph in Mr. Spence's Paper, namely, that Lloyd's now require that all seacocks fitted with the Kingston valve should be above the level of the stoke-hole floor. It seems to me that this provision, although very valuable, only thrusts aside the evil, and does not at all cure it; because the Kingston valve may get out of order, and is liable to be smashed by accident just as much as the cocks fitted directly to the skin. It lessens the danger, but it does not annihilate it. I think Mr. Spence's invention is a step in the right direction; and although I agree with some that it may not be wholly successful, yet it deserves testing and very serious consideration.

Admiral DE HORSEY: The last speaker has said very much what I myself intended to say—that Mr. Spence's plan, although perhaps not applicable to all ships, is decidedly a step in the right direction. It is a very unpleasant thing to find the water running into your ship, and not to know where it comes in. It happens to have been my lot to have been in that position in a vessel I commanded about twenty-three years ago, off the coast of Nova Scotia. I found the ship filling, and could not say where the water came in. By going up to my neck in water I did ultimately find it out. The engineer was a little sea-sick, and had left the bilge injection open, and at the same time had his sea injection open. We very nearly went to the bottom from that cause. It appears to me that the plan which Mr. Spence proposes is inapplicable to large ships for the reasons which have been said. The valve would be an enormous one, and I should be very sorry to have such a valve in a ship. It is questionable whether it might not be applied in several places, and whether you might not limit the number of holes in the ship to, say two in each bilge, these would be clearly within the knowledge of the engineer; but as it is at present, if you find your ship leaking, there are so many holes that it is hardly practicable to discover where it is until it is too late.

Mr. E. C. WARREN: I wish to say a word or two with reference to Mr. Morley's Paper. I was very much interested to hear his statement, and several of the remarks which he made towards the end of his Paper were especially good. In one of them he says that, as far as his experience goes, means should be provided for closing all ventilators in case of fire. He thinks that has not been attended to. There is one other thing which I should like to point out to this Meeting—it has especially to do with iron-clads, where they have armoured decks, and those armoured decks are below or at the level of the water, with a ventilating trunk running fore and aft under the deck, and branch pipes leading into it from the various water-tight compartments. I think special arrangements should be made for the purpose of closing these branch pipes in the different compartments, and that they should only be opened when absolutely necessary. There are some ships in existence now which if injured in the outer bottom below the water-line would fill through their own ventilating pipes in various parts of the ship, and a great deal of water might get into the ship without anyone having any knowledge of it. I wish to

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point that out to Mr. Morley, and I think if he incorporated that suggestion in his Paper it would be a most interesting one. Some people will say we have valves at the water-tight bulkheads. But these are always kept open for the purpose of ventilation, and before you can close all of them you may have a large quantity of water in the ship. In these low ships, such as the *Popoff*, it is very necessary, I think, to attend to that. I would just, also, make this remark:—It was very interesting to hear what Mr. Martell said as to the Council of this Institution sending Resolutions and Suggestions to the Government on this new Shipping Bill, which is another illustration of how little the Members know of what is going on in the Institution.

The CHAIRMAN (Mr. J. Scott Russell, F.R.S.): It, perhaps, becomes my duty, after the remarks we have heard, to say a word or two upon the subject which Mr. Martell has mentioned. I have an impression that the information which was sent forward to the Board of Trade was such as Mr. Martell would certainly approve of, from its negative character; and I think there was not in the information sent forward any matter to which his remarks—according to the impression they gave me—could possibly apply. If I were to give a mere personal opinion upon the subject, my personal opinion would be this—that there could be nothing, possibly, in the slightest degree, objectionable to any shipowner in anything which the Committee sent forward. I believe there could not be the slightest objection to Mr. Martell having a copy of this very negative Resolution; nor, indeed, any Member who could have the slightest wish to possess it. I only do not say so because, of course, I am not the Council, and cannot speak in the name of the Council; but I think, in the first place, the Paper that was sent forward is perfectly innocuous; and, secondly, I do not think there could be the slightest breach of propriety in any Member, who cares to see it, asking the Secretary to show it. Perhaps Mr. Martell will excuse me for not going further. Now, I am sure we are obliged to Mr. Morley and Mr. Spence for the very laborious Papers they have read to us; and although the subject may not appear so large a one as some of the subjects which have been much discussed at these Meetings, yet I do consider that an accumulation of little matters—of little dangers of the kinds alluded to—are of the most serious nature. I think that if you could combine great simplicity with such precautions as have been stated they would be of very great value. I observe that the two sets of plans—Mr. Morley's and Mr. Spence's—were, apparently, contradictory in this respect; that Mr. Morley seemed to me to get a great number of valves, and a very great number of communications, and a very great number of pipes; and it might be said, with regard to Mr. Spence's plan, that he had too many eggs in one basket. It shows, therefore, the great advantage of such a Meeting as this; because I have no doubt that each of these two gentlemen will go away from here determined that all the good qualities that belong to the plan of the one shall be added to his, and all the good qualities belonging to the other shall be added to his. As it stands, I am sure you will be much gratified if Mr. Spence and Mr. Morley have anything to say which they think would clear away any point that has not been brought up in this Discussion. It is so very late, that I must ask them to give us the greatest mechanical effect in the shortest space of time.

Mr. MORLEY: With regard to Mr. Martell's observations, I carefully avoided giving any opinion as to the practicabilty or impracticability of putting water-tight compartments in merchant ships, or in ships of war. The point I wish to urge particularly is—that greater pumping power is desirable in either case, and that ejectors are especially applicable to merchant ships.

The CHAIRMAN: You try to give the maximum pumping power?

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Mr. MORLEY: Yes. I quite agree with the remarks which were made by Mr. Warren and I feel much indebted to him for mentioning my Paper so kindly as he did, also for pointing out the danger arising from ventilating pipes which pass through water-tight bulkheads. I have often looked at such pipes, and have felt that they were sources of danger; people would forget to shut the valves in them if any emergeney arose, and water would get through. Then with regard to your observation, Sir, about the number of valves, I should like to explain that every Kingston valve has a stop-cock inside the valve; so that, before the water can get into the ship, the valve must be opened, and also the stop-cock; and in each case these are opened by rods from the main deck. So that the rules which have been made with regard to the valves being under the stoke-hole plate, and so forth, in connection with the engine to which Mr. Spence refers, certainly were not required for the pumps of the ships which I had to speak of. It only remains for me to thank you for the attention which you have given to the Paper.

Mr. SPENCE: It is, I must say, some satisfaction to me to find that none of you have found great fault with my arrangements. I think Mr. Merrifield was the only one to find a little fault, and that was on account of the fear he had that small fish, or something else, would be drawn into the valve. "The proof of the pudding is in the eating;" and, as the valve has been fitted on a ship for three years, going to all parts of the world, and has been found to be a success in every respect, and has not swallowed up any small fish, I think there is not so much fault to be found with it. Mr. Parker stated, I think, that about eighteen months ago—when this matter was brought before him—he examined all the steamers, and put all the sea connections in proper order, so that no accident could occur. It is rather unfortunate, but just about a year ago, on the 5th of May, 1875, one of his ships came to grief in Bombay, as stated in my Paper. With regard to the *Rover*, I am exceedingly sorry I mentioned it; but in future, if the Admiralty would give full details to the newspapers of the accidents that happen to their engines, ship-builders would not be apt to get a wrong impression into their minds as to the way in which they get the water into them.

The CHAIRMAN: I am very sorry that we shall be obliged to postpone till a more convenient opportunity a very interesting Paper which is left on the list. Time gallops very fast; and I am afraid we must deny ourselves that pleasure till possibly to-morrow morning.

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ON THE UNEQUAL ONWARD MOTION IN THE UPPER AND LOWER CURRENTS IN THE WAKE OF A SHIP; AND THE EFFECTS OF THIS UNEQUAL MOTION ON THE ACTION OF THE SCREW-PROPELLER.*

By Professor Osborne Reynolds.

[Read at the Seventeenth Session of the Institution of Naval Architects, 7th April, 1876; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

The very important part which the tendency of the water to follow in the wake of a ship plays in the action of the screw-propeller has often been the subject of remark. It has been very prominently brought forward by Mr. Froude and others; and is, I believe, now very generally accredited a place in all considerations of the very complicated phenomena which envelop the action of the screw. There is one effect of this wake, however, which I think has not hitherto received the attention which its importance demands, and this is the object of my present communication.

Of the various phenomena which have been developed during our experience of screws, none have given more trouble than their tendency to cause vibrations; and although certain causes have been suggested for this, it has never received a satisfactory explanation. This, I think, arises from the fact, that in the calculations and estimates which have been made hitherto respecting the screw, it has been uniformly assumed that the blades of the screw act with equal effect in all positions—that the screw acts equally on all the water through which it sweeps. If this assumption were correct there could be no tendency in the screw to cause vibrations except by throwing water against parts of the ship. But this equal action can only be assumed to exist on the supposition either that the water through which the screw moves is initially at rest, or that it is all moving with the same velocity. Now this supposition will, I think, on closer examination, be seen to be very far from true; and in recognising what is the actual condition of the water, I think we can see what are the causes of general phenomena which have been hitherto only partially explained, besides the above mentioned tendency to cause vibrations which is the *péché habituel* of the screw-propeller.

* Received 18th March, 1876.

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Last year, while investigating the action of a screw on the steering of a vessel, my attention was drawn to the tendency which the screw had to turn the ship out of her direct course. This tendency I found was very generally recognised, and was attributed, like the tendency to cause vibrations, to the action of the water thrown by the screw obliquely against the stern-post.

That this explanation was not the true one, I was at once able to convince myself by removing the stern-post, when I found that the tendency of the screw to turn the ship out of her course was increased. I was thus led to conclude that the upper blade or blades of the screw experienced greater lateral resistance than the lower blade or blades; for the stern of the ship was always driven in a direction opposite to that in which the upper blades were moving. On looking for the cause of this resistance it appeared that it might arise from the water in which the upper blades worked following the ship faster than that below; and on comparing the various tendencies which the ship had to turn when moving at different velocities, with what might be expected to result from such an unequal motion, I found sufficient agreement to confirm me in this opinion. Being at that time concerned with the steering, I only examined this phenomenon so far as it related to the investigation in hand, the results of which investigation were contained in a Paper read before Section G at the British Association last year. Subsequently, however, it occurred to me that this difference in the speed of the following currents must play an important part in the action of the screw-propeller, particularly as regarded the vibrations.

The Relative Speed of the Upper and Lower Currents in the Wake.

As is well known, a ship imparts an onward motion to the water in its wake in two ways—by the friction of the skin, and by the wave which follows the ship. From neither of these causes does it appear that the motion imparted to the water will be equally distributed through the whole area of the wake; but, on the other hand, it appears that both causes will act to give the water near the surface a greater onward velocity than that which is on a level with the keel of the ship, and to give that water which is directly behind the stern-post a greater velocity than that which is more on one side.

When a long narrow plane is dragged through the water in the manner adopted by Mr. Froude in his experiments on surface friction, its only effect, in the way of setting the water in motion, is that of skin-resistance; but even here the upper water will be made to move faster than the lower. The motion imparted to the water in the immediate vicinity of the plane is rapidly communicated to the adjacent water, and so becomes more or less dissipated. Now at the top of the plane the only direction in which this dissipation can extend is laterally, whereas towards the bottom of the

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plane the dissipation can extend downwards as well as sideways, and is therefore much more rapid, leaving the water near the bottom of the plane moving with less velocity than that near the top. So that, looking at a ship as a long narrow plane, we see that even so there would be not only a difference between the velocity of the water in the middle of the wake and that towards the outside, but that there would also be a difference in the velocity at different elevations. A ship, however, differs considerably from a plane, and its form tends further to increase the inequality in the motion of the water.

The water which fills the opening left by the ship in large part rises up from beneath its bottom, and in rising carries up to the surface that water which has received the greatest onward motion from rubbing against the skin, supplying its place below by fresh water without any onward velocity. This would be the case even if the run of the ship were in the form of a vertical wedge, and the actual form of the ship, which is more like an inclined plane than a vertical wedge, tends greatly to increase this action, for the water moves upwards along what are called the geodetic lines.—*See Rankine's Shipbuilding*, p. 83.

The fact that the lines of a ship are much fuller near the surface than those below tends also to give the upper water greater forward motion.

Again, the form of a ship is such as to cause a wave to follow it, the crest of the wave being not far from the stern-post. This wave also causes a greater onward motion in the particles of water near the surface than those which are below.

We see therefore, taking all the causes together, that there is probably a very considerable difference in the relative onward velocity imparted by the ship to the water in which the upper and lower blades of the screw work. There is also a difference in the velocity of the water at different lateral distances from the middle of the wake, but this latter variation is not of any direct importance as regards the object of this communication and therefore will not be considered further.

The Actual Velocity of the Wake.

Before we can form an estimate of the probable magnitude of the actual difference in the velocity with which the upper and lower currents move, it is necessary to arrive at some conclusion as regards the proportion which the velocity of the wake bears to that of the ship. The actual motion imparted by a ship to the water in its wake has never, so far as I am aware, been experimentally investigated; there are however two ways in which estimates have been formed;—by observations on the surface, and by calculations based on the resistance of the ship.

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If one may judge from various incidental comments, one finds that the observation of the motion at the surface of the wake has led to much higher estimates of its velocity than the calculations from the ship's resistance.

Mr. G. B. Rennie remarks, "The current caused by the onward motion of the ship "has a velocity at the stern equal to that of the ship itself."*

Mr. Griffiths says, "The water in which the screw works is an eddy which follows "the ship at the same speed or nearly so. * * If a patent log were placed in the screw "opening, it would not even approximately indicate the speed of the ship."†

I would remark here that I do not make these quotations in order to show that they are wrong, but simply to show that observation of the surface has led those who have had the best opportunities of judging, to form a high estimate of the onward motion imparted to the wake for the purpose of comparing this estimate with that based on the resistance of the ship.

In his *Marine Engineering*, Rankine gives a rule for calculating the velocity of the wake (*see* p. 249); and applying this rule to the *Warrior* (a very long ship), he finds that the speed of the water near the stern-post is ·09 the speed of the ship.

We see, therefore, how widely this estimate differs from the estimates formed from observations at the surface. The previous argument, however, regarding the difference between the velocity at the surface and that below will go a long way to reconcile these estimates.

Rankine's estimate is based on the supposition that all the water following the ship has the same onward motion imparted to it. A very different result, however, is arrived at, if instead of the entire mass of water in the wake it is only, or principally, the upper layers that are supposed to be set in motion. The speed imparted to the water must be inversely proportioned to the volume acted on, so that if the motion only extends to the bottom of the ship, and gradually dies out, instead of the velocity being 10 per cent. it will be 20 per cent. that of the ship.

This seems to me to agree with what may be observed on looking over the stern of a paddle steamer, or a sailing ship. In the case of the steamer, the inner ends of the lines of foam left by the paddles become curved forwards as they approach the stern, where they join the wake, and are violently dragged forward with a velocity of certainly more than one-tenth that of the ship.

As a rough estimate, therefore, I should conclude that in a ship with a fairly fine run the velocity of the wake, at the surface, is not less than ·20 that of the ship, while

* *Modern Screw Propulsion*, p. 19. By N. P. Burgh. † *Ibid*, p. 45.

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at the level of the keel the water is practically stationary. And, in the cases of ships, moving at an abnormal speed, carrying a high stern wave, or having full sterns, the difference may be increased to almost any extent.

The Effect on the Screw.

Having now shown that there is a considerable difference in the onward velocity in different parts of the ship's wake, it only remains to consider what effect this difference would have on the action of the screw.

Compared with the speed of the ship the difference is after all but small, and if the thrust of the screw depended on the speed of the ship, this small difference might well be neglected; all that would result would be a difference of some 20 per cent. in the pressure on the upper and lower blades. I cannot help thinking that it is owing to some such confusion as this between the action of the screw and the speed of the ship that the unequal motion of the water in the wake has remained unattended to for so long. When we realize the fact that the thrust of the screw does not depend on the speed of the ship, but on the difference between the speed of the ship and the geometrical speed of the screw, as the speed at which it would have to move forward were the water unyielding; and that this difference, called the slip, is somewhere between one-tenth and one-fourth the speed of the ship, we see at once what an important influence an increase in the speed of the water anything like one-fourth the speed of the ship would have. Hence, although the inequality in the motion of the water is small as compared with the speed of the ship,—as compared with the slip it is very large, and this is the essential comparison.

The slip of a screw would be somewhere between one-tenth and one-fourth the speed of the ship if it were equally distributed over the entire area through which the screw acts. But if there is a difference in the rate at which the water is following the ship at different parts of the section of the screw race, then the slip, and consequently the pressure on the blades of the screw, will be greatest at those places where the water is following the ship fastest.

Taking the mean slip at ·2, and supposing the upper blades to be working in a current which has an onward velocity ·2 greater than that in which the lower blades are working, then the slip at the tops of the upper blades would be ·3, and that at the tops of the lower blades only ·1; so that the resistance at the tips of the upper blades would be three times as great as that at the tips of the lower blades. Or, to put it roundly, the area of the water on which the screw acts to drive the ship forward would be virtually reduced; it would be the blades above the shaft that principally drive the ship, the lower blades merely passing through the water.

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The Tendency to cause Vibrations.

Under these circumstances it is clear that the lateral resistances which the upper and lower blades encountered would no longer balance each other. For example, on a two-bladed screw the pressure on the blades would only be equal when they were both on a level with the shaft. As the one rose towards the vertical position the resistance on it would increase, while that on the lower blade would diminish. The action of the screw would, therefore, be to cause an intermittent force, urging the stem in the direction opposite to that in which the tips of the upper blades were moving.

The magnitude of this intermittent force would be very considerable; under the circumstances assumed above, it would, while it acted, be comparable to the entire lateral resistance encountered by the screw. It would, therefore, afford sufficient explanation of the screw's tendency to cause vibrations, which the shock caused by the water thrown by the screw against the stern-post does not. It would also fully accord with what experience has shown respecting the effect of the screw on the steering of the ship.

Effect on the Efficiency.

Such an inequality in the action of the screw as that described above, would not necessarily reduce its efficiency as a propeller. So long as there was some small slip left to the bottom blades there could be no actual retardation of the ship. But if the inequality in the motion of the water should at any time bear such proportion to the mean slip that the lower blades could not, as it were, screw themselves through the water fast enough to keep up with the ship, then they would have to be dragged through the water, and would retard the ship. Such a result would only be experienced when the inequality of motion in the water was more than double the mean slip of the screw. Such a state of things, it would appear, could only be brought about by a vessel moving at an abnormal speed and carrying a large stern wave, or by a vessel having a very full stern—conditions which are invariably found to result in loss of efficiency and excessive vibration, and very often in what is called negative slip. The loss of efficiency which usually attends negative slip has received what appears to be a satisfactory explanation as being due to the back suction, or reduction of pressure which the action of the screw causes on the stern of the ship. And that it is in some part at least due to this cause has been proved by Mr. Froude by actual experiment. But, considering that when this action occurs, all the conditions which would cause the lower blade to drag back are known actually to exist, it would seem to be highly probable that at least in part the loss of efficiency, as well as the excessive vibration, is due to the unequal motion of the water on which the upper and lower blades of the screw act.

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Disadvantage of Large Screws.

It can be easily seen that the effects which have been attributed to the unequal motion of the water would be greater with screws, which are larger in proportion to the draught of the ship than with those which are smaller.

There are two reasons for this. In the first place the larger the screw the smaller must be the mean slip, and consequently the greater would be the proportion which the inequality of the motion of the water would bear to it. On the smaller would be the margin allowed for the difference in the slip at the top and bottom of the blades. And, secondly, the larger the screw the greater would be the difference in the motion of the water in which the upper and lower blades worked.

Now I believe it has been found, as a matter of experience, that there is a limit to the size of screws which give the best results for each ship. This limit is doubtless in part owing to the increased friction which large screws experience, owing to their increased surface; but the friction must be much larger than what we have reason to suppose it is, if this alone can account for the limit. It seems probable therefore that this limit is another result of the inequality of the motion of the following waters.

A few years ago a large Atlantic steamer was fitted with a screw, which could be lowered until its blades extended below the bottom of the ship. Various advantages would appear as likely to result from such an arrangement. But it seems to me to be probable that the disadvantages resulting from the inequality in the motion of the wake would be considerably increased, for the lower blades of the screw would descend into the water with no following motion at all, while the upper blades would still be high up in the wake. I do not know what was the result of the experiment, but I have heard that the plan had to be abandoned on account of the excessive vibration.

Conclusion.

It is not my object in this Paper to enter upon the question as to what modification in the construction or dispositions of screws might be suggested by the recognition of the unequal motion of the wake and its effects. Any suggestions I might make would be premature. My endeavour has been solely to elucidate further the actual conditions or circumstances of the problem of screw propulsion, it being my conviction that a complete knowledge of the conditions of any problem must be conducive to its eventual solution. My opportunities of studying the action of screws are limited; and in venturing to come before you, my inducement has been that my ideas would be

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criticised by those who have much better opportunities. If, through ignorance, I have been occupying time by dilating upon what is unimportant or already known, I can only hope that I may have your indulgence; a claim which I feel entitled to make, as it is only the importance which you were pleased to attach to my former communication which has emboldened me to come forward again.

DISCUSSION.

Mr. J. Scott Russell, F.R.S. I should be sorry if this Paper passed without comment upon it. I think it is a very valuable Paper, and very much that Professor Reynolds has said is profound and valuable truth. The only element I would call his attention to very strongly is this, that the distribution of those currents in the stern of the vessel is very materially altered by each form of stern of the ship, What those peculiarities are I think he will be able to guess and to calculate. At all events I think it a very valuable Paper, that the direction of thought is very important, and with a great deal of what he has said as to what takes place in the stern of the ship by the action of the screw I entirely agree.

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ON STEEL FOR SHIPBUILDING AS SUPPLIED TO THE ROYAL NAVY.*

By JAMES RILEY, Esq., Manager of the Landore Siemens-Steel Works.

[Read at the Seventeenth Session of the Institution of Naval Architects, 7th April, 1876; the Right Hon. LORD HAMPTON, G.C.B., D.C.L., President, in the Chair.]

THE purpose of the present Paper is to show what has been done by the Company (of whose works the author is the Manager), towards producing a material for shipbuilding which shall meet the requirements indicated by Mr. Barnaby in his Paper on "Iron and "Steel for Shipbuilding," read before the Members of your Institution twelve months ago. This being so, the closing sentences of that Paper may well be quoted at this point. They are as follows:—

"The uncertainties and treacheries of Bessemer steel, in the form of ship and "boiler plates, are such that it requires all the care which it has bestowed upon it at "L'Orient to avoid failure. The question we have to put to the steel makers is, What "are our prospects of obtaining a material which we can use without such delicate "manipulation, and so much fear and trembling? We have gone on for years, using "iron plates which are a compound of impure irons, of different and unknown "qualities, welded together imperfectly in the rolls. We want a perfectly coherent and "definitely carburized bloom, or ingot, of which the rolls have only to alter the form "in order to make plates with qualities as regular and precise as those of copper and "gun metal, and we look to the manufacturers for it.

"I am ready, for my part, to go further than the French architects have gone, and "build the entire vessel, bottom plates and all, of steel; but I know that at present the "undertaking will involve an immense amount of anxiety and care. We ought not to "be behind any other country in this matter, and it shall not be my fault if we are."

Long previous to the date when these words were spoken, it had been the desire of Dr. Siemens that the Landore Siemens-Steel Company should turn their attention to

* Received 23rd March, 1876.

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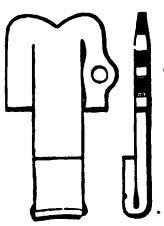
the production of steel of the finer qualities, whether of soft or hard descriptions; consequently, a series of experiments, extending over some months, had been conducted with a view to the manufacture of plates, angles, &c., suitable for shipbuilding and boiler-making; in fact, of such material as was described by Mr. Barnaby. Such being the case, it seemed a fitting opportunity for calling his attention to what had been accomplished at Landore,—and the author, with Mr. Gordon, the managing director, having obtained an interview, informed Mr. Barnaby that the Landore Company were disposed to accept the challenge already quoted.

Not to detain you, it will be sufficient to say, that after the lapse of some months, devoted to the testing of specimens of steel supplied by the most eminent firms in this country, a contract was entered into between the Admiralty and the Landore Company, for the supply by the latter of the plates, angles, and beams, to be used in the construction of two armed despatch vessels, the *Iris* and *Mercury*, to be built at Pembroke Dockyard. The author hopes to be able to convince you, by a statement of the tests which have been applied to the steel supplied, and more conclusively by the specimens put before you, that a material equal, if not superior to that manufactured in any other country, and having most of the properties and desirable qualities, with almost none of the disadvantages mentioned by Mr. Barnaby, is now being made and supplied for shipbuilding and other purposes to Her Majesty's Government.

By the favour of Mr. Barnaby I am able not only to describe various tests to which the material has been subjected at Pembroke Dockyard and elsewhere, but also to exhibit specimens showing the effect produced; and acting under the impression that it would probably add to your interest and convenience if diagrams were prepared and placed before you, showing the changes of form the various specimens had assumed after undergoing the severe tests applied to them, this has accordingly been done, and I trust upon such a scale as to be easily distinguishable.

I propose to give a rapid description of these specimens before passing on to an account of the manner in which the different qualities of the metal have been proved. For convenience they are divided into Hot Forge Tests and Cold Tests.

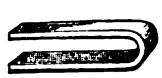
Hot Forge Tests.



TEST 1.

1.—A piece of $\frac{1}{2}$-inch plate, subjected to the ram's-horn test, the lower end being doubled close while cold, without fracture.

2.—Shearings of $\frac{1}{2}$-inch plate, about $1\frac{1}{2}$ inch wide, welded together, and bent in the weld to a radius of $\frac{3}{4}$-inch without fracture.



TEST 2.

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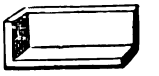
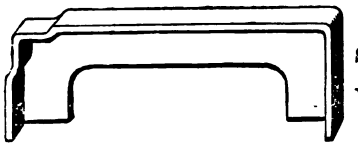
3.—Two pieces of plate welded together, and bent in the parts welded, one to an angle of 90°, and the other to an angle of 105°, without fracture.

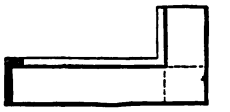
TEST 3.


TEST 4.

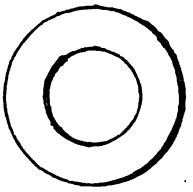
4.—A box end, made from ½-inch plate to form angle steel, 3 inches by 3½ inches by ½ inch. It is soundly welded, and is in every respect as sound as one made from angle iron.


TEST 5.

5.—An intercostal, made from ½-inch plate, to form angle steel, 3½ inches by 3 inches by ½ inch, soundly welded, and considered a good job.


TEST 6.

6.—An outside corner, made from ½-inch plate, to angle steel. This is a fair average weld, these corners being much more difficult to make than inside corners, as the gusset piece has to be welded in after being fitted.

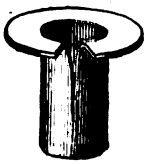

TEST 7.

7.—Two pieces of plate, 2½ inches by ½ inch, welded together straight, then turned after its edge to form a circle 6 inches in the clear. It is a sound weld, and there is no fracture in the turning.

TEST 8.

8.—Two pieces of plate 3 inches by ½ inch welded together, and bent off at right angles. It is soundly welded, and bent to the form shown without fracture.

10.—A piece of plate 21 inches by 10 inches by ½ inch, turned to the form of a tube (not welded), then placed in a flanged socket, and a flange pin forced into it by blows from a 60-cwt. steam hammer. It assumed the form shown after eight blows. Stood well.

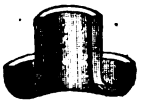

TEST 10.

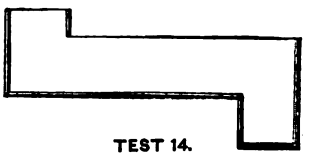
TEST 11.

11.—A piece of ½-inch plate, 12 inches diameter, forced into a socket by blows from a steam hammer, to the form shown. Stood well.

12.—A piece of ½-inch plate, dished to form shown No. 11, then flattened back nearly to its original form. Stood well.

13.—A piece of ½-inch plate, 12 inches in diameter, forced into a tube, then flanged back on the anvil to the form shown. Stood well.


TEST 13.


TEST 14.

14.—An outside and inside corner, made from angle steel, 6 inches by 3½ inches by $\frac{7}{16}$-inch, welded sound, but with more difficulty than in welding iron.

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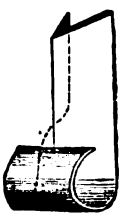
The authorities at Pembroke stated, however, that no doubt was entertained but that with more experience these welds could be made satisfactorily, and I may add that this is now being done.

TEST 15.

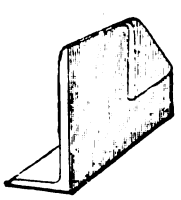
15.—An inside corner and box end, made from angle steel, 6 inches by $3\frac{1}{2}$ inches, by $\frac{7}{16}$-inch, welded satisfactorily.

16.—A piece of angle steel, 6 feet long, 6 inches by $3\frac{1}{2}$ inches by $\frac{7}{16}$ inch, the web closed together at one end, and the other opened out and turned back to the form of a ring, as shown. Stood well.


TEST 16.

Before passing on to the cold tests I ought to state, that although these forge tests show how the steel can be used and manipulated, yet I by no means wish it to be understood that if ordinary Bessemer steel were subjected to the same tests it would fail under them; it is nearly certain that the reverse would be the case; in fact, the authorities at Pembroke Dockyard state as much; but they add, that when the best Bessemer steel they have had was subjected to the cold tests, the difference in favour of Landore steel was most marked. I have therefore the more pleasure in calling your attention to them, believing, as I do, that they are unequalled in steel, and scarcely matched for ductility by the finest iron.

Cold Tests.


TEST 1.

1.—A piece of 6 inches by 3 inches by $\frac{7}{16}$-inch angle, with the corner bent over and flattened close by blows from a 40-cwt. steam hammer. No fracture.

TEST 2.

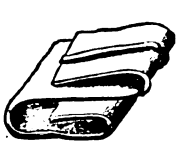
2.—A piece of 3 inches by 3 inches by $\frac{3}{8}$-inch angle, 1 foot long, flattened out by two blows of steam hammer. No fracture.

TEST 3.

3.—A piece of 3 inches by 3 inches by $\frac{3}{8}$-inch angle, 1 foot long, closed by two blows of steam hammer. No fracture.

TEST 4.

4.—A piece of 3 inches by 3 inches by $\frac{3}{8}$-inch angle, 1 foot long, flattened out same as No. 2, after which the wings were turned back over the outside angle. Slight fracture at the ends only.


TEST 5.

5.—A piece of 3 inches by 3 inches by $\frac{3}{8}$-inch angle, 18 inches long. After being flattened out, as in the previous cases, the two ends were turned over in opposite directions; the piece was then doubled up in the middle, and closed by hard blows from a steam hammer. There is no fracture, but there are cuts from the hammer tool in one place, and from its own angle in another.

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6.—A piece of 3 inches by 3 inches by $\frac{3}{8}$-inch angle, 18 inches long, dealt with as in the specimen last mentioned, except that before bending one end over the wings were bent back, as in No. 4. There is a slight fracture, as shown, caused by its own angle.

TEST 6.

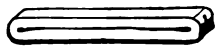
TEST 7.

7.—A piece of $\frac{5}{8}$-inch square bar, formed into a knot, occupying only $4\frac{1}{4}$ inches by 3 inches space. No fracture.

8.—A piece of $\frac{3}{4}$-inch round bar, formed into a knot, occupying only 3 inches by 2 inches space.

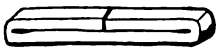
9.—A piece of $\frac{1}{2}$-inch round bar, formed into a knot, occupying $2\frac{1}{4}$ inches by $1\frac{1}{2}$ inches. This is a very fine specimen.

10.—A ring, 5 inches in diameter, made from two pieces of plate welded together, and closed by blows from a sledge hammer. No fracture.



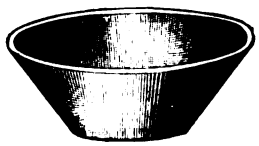
TEST 11.

11.—A similar ring, made from Low Moor iron, closed by one blow from 60-cwt. steam hammer. There are slight fractures where bent, as shown.



TEST 12.

12.—A similar ring, made from Landore steel, and closed in the same manner. Fractured in the weld, as shown.

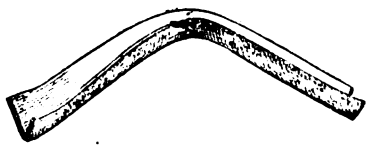


TEST 13.

13.—A piece of $\frac{1}{2}$-inch steel plate, 12 inches diameter, dished to $3\frac{1}{4}$ inches deep by five blows from a 60 cwt. steam hammer. Without fracture.

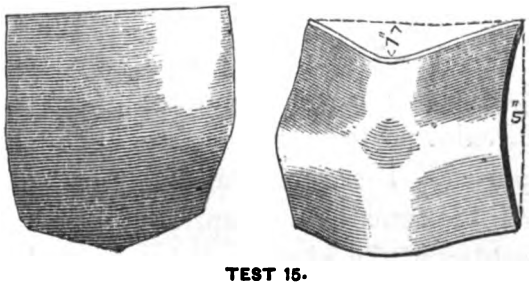
A piece of steel from an eminent firm, similarly treated, broke into three pieces at the fifth blow.

14.—A piece of 6 inches by 3 inches by $\frac{7}{16}$-inch angle, had the wings closed in, as shown; it was then placed edgewise, on bearings 5 feet apart, and bent by hydraulic pressure to a deflection of $12\frac{1}{4}$ inches. A piece of Best Best angle iron, similarly treated, broke at deflection of 6 inches.



TEST 14.

15.—A piece of plate, 3 feet by 3 feet by $\frac{1}{2}$ inch, had an iron block placed under each corner, 9 inches from the edge, and an iron ball, weighing 1,291 pounds, was dropped on the centre, from a height of 30 feet. Bent, as shown, without a sign of fracture.



TEST 15.

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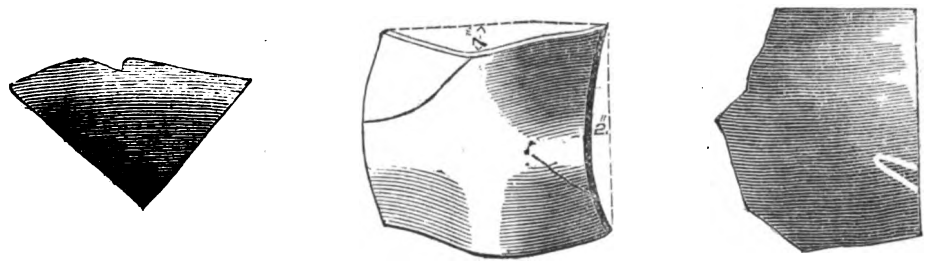
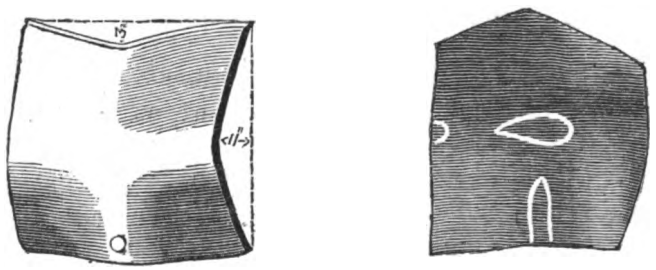
16.—A piece of steel, from an eminent firm, similarly treated, was bent and fractured, as shown.



TEST 16.

17.—A piece of Best Best iron, similarly treated, was bent and fractured, as shown.

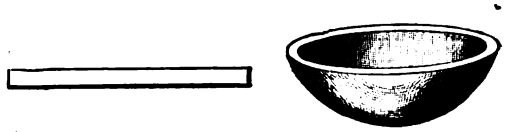


TEST 17.

18.—A beam piece, 4 feet 6 inches long, made of $\frac{5}{16}$-inch plate, 5 inches deep, with double angles, $2\frac{1}{2}$ inches by $2\frac{1}{2}$ inches by $\frac{5}{16}$-inch, on upper and lower edges, riveted together with $\frac{5}{8}$-inch rivets, $3\frac{1}{2}$ inches diameter apart, was bent under hydraulic pressure to the form shown, without fracture, when the fixings failed. It was removed before the test could be completed.

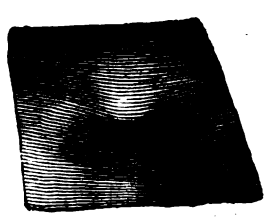
TEST 18.

19.—A piece of $\frac{3}{4}$-inch plate, 12 inches diameter, forced by hydraulic pressure through a ring 10 inches diameter, and dished to the form shown, that is, $3\frac{1}{2}$ inches deep, by a pressure of $145\frac{1}{2}$ tons, without fracture.



TEST 19.

20.—A piece of $\frac{3}{8}$-inch plate, rested during experiment upon a perfectly horizontal surface of an annular iron anvil; a central circular portion of the plate, 12 inches in diameter, being unsupported. The anvil was firmly embedded in the ground. A charge of 18 ounces of compressed gun-cotton was suspended over the centre of the plate, an air space of 3 inches intervening between



TEST 20.

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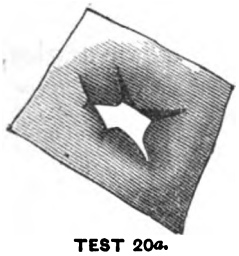
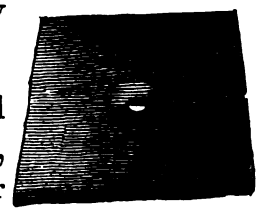
the upper surface of the plate and the base of the charge. The charge was exploded by detonation.

The result is, that the plate is dished down to the extent of $1\frac{1}{2}$ inches, but there is no sign of fracture.



TEST 20*a*.

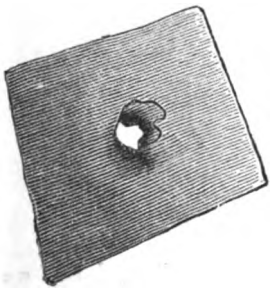
20*a*.—A piece of $\frac{3}{8}$-inch Best Best iron, similarly tested, is almost shattered to pieces.



TEST 21.

21.—A piece of plate, $\frac{11}{16}$-inch thick, supported on anvil as above. Charge of gun-cotton 10 ounces, and 3 inches in diameter, placed upon the upper surface of the plate in a central position, and exploded by detonation.

The result is that a hole $1\frac{1}{2}$ inches diameter is made in the centre of the plate, and that for $\frac{3}{4}$ inch all round this hole, the plate is beautifully cupped or countersunk, as if it had been done by a cutting tool. There are no lateral fractures in the plate.



TEST 21*a*.

21*a*.—A piece of Best Best iron plate, $\frac{11}{16}$-inch thick, similarly treated, was fractured as shown.

TEST 22.

22.—A piece of plate doubled close up, four-fold, as shown, without fracture.

23.—A narrow strip of plate, 2 inches by $\frac{1}{2}$ inch, twisted into the form shown.

TEST 23.

It may be well, before presenting further statements of the different tests, with their results, that you should be informed of the requirements of the Admiralty with regard to the materials to be supplied under the contract previously referred to. These are as follows:—

From every plate made a strip is to be cut, which, after being heated to a "cherry "red" colour, shall be plunged into water having a temperature of 82° Fahrenheit. After being thus cooled, the strip is to be bent, without fracture, until the radius of the inner curve equals not more than $1\frac{1}{2}$ times the thickness of the strip. This is known as the "tempering test." Further, from each lot of 50 plates or angles a piece is to be taken, and the edges having been planed parallel, its tensile strength is to be proved. To be satisfactory, this must not exceed 30 tons, nor be less than 26 tons on the square inch, and before fracture takes place there must be an elongation of not less than 20 per cent. on 8 inches of its original length. These tests are applied in the presence of a

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resident representative of the Government, and I am glad to be able to state that up to the present moment not a single lot of all that have been placed before him has been rejected for failing to satisfy these tests, only five out of the whole number tested not having passed the limits of tensile tests, and these proving satisfactory in other respects, have been accepted.

Up to the time of writing, 101 samples, representing over 5,000 plates or angles, have been subjected to the tensile test, with the following results :—

Number of Test Pieces.	Breaking Strain in Tons, per square inch.	Average Elongation in 8 inches.
1	25 to 26	2·00 inches
20	26 „ 27	2·00 „
24	27 „ 28	2·03 „
28	28 „ 29	1·93 „
24	29 „ 30	1·89 „
2	30 „ 31	1·96 „
2	31	1·78 „
101	Mean, 28·16 tons.	1·94 in., or 24·25 %

In his Paper Mr. Barnaby gave the tensile strength of Best Best iron as 22 tons when tested with the grain, and 18 tons when tested crosswise. In certain experiments by Mr. Kirkaldy on two very fine plates manufactured at Borsig's Works, Berlin, and, I believe, stated to be homogeneous, the tensile strength was found to be lengthwise 23·84 tons, and crosswise 22·6 tons. When similarly tested the Landore steel gave lengthwise 28·85 tons, crosswise 28·2 tons; the comparison, therefore, stands thus :—

	B. B. Iron.	Borsig's Plates.	Landore Plates.
Lengthwise ...	22 tons	23·84 tons	28·85 tons
Crosswise	18 „	22·60 „	28·20 „
Difference ...	4 tons, or 18·18 %.	1·24 tons, or 5·20 %.	·65 tons, or 2·59 %.

These results are confirmed by the following Table, showing a series of experiments conducted by Mr. Kirkaldy, in which the difference between the tensile strength lengthwise and crosswise is only two-tenths of 1 per cent.

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SUMMARY OF THE RESULTS OF EXPERIMENTS TO ASCERTAIN THE ELASTIC AND ULTIMATE TENSILE STRENGTH OF SIX STEEL PLATES, RECEIVED FROM MESSRS. THE LANDORE SIEMENS-STEEL COMPANY (LIMITED).

Test No.	Description.	Thickness.	Stress.		Rate of Elastic to Ultimate.	Contraction of Area at Fracture.	Stress per Square Inch of Fractured Area.	Extension.		Appearance of Fracture.
			Elastic per Square Inch.	Ultimate per Square Inch.				At 60,000 lbs. per Square Inch.	Ultimate.	
Lengthway.										
J		inch.	lbs.	lbs.	Per Cent.	Per Cent.	lbs.	Per Cent.	Per Cent.	
1,341	Unannealed ...	·37	34·600	72·880	47·4	37·5	116·734	4·50	22·3	Silky.
1,371	Ditto ...	·71	30·400	66·905	45·4	44·7	121·179	6·75	24·5	Ditto.
	Mean ...		32·500	69·892	46·4	41·1	118·956	5·62	23·4	Silky.
1,343	Annealed ...	·37	31·500	67·520	46·6	43·1	118·681	8·00	24·8	Silky.
1,347	Ditto ...	·40	31·200	66·410	46·9	44·7	120·199	8·08	21·1	Ditto.
1,353	Ditto ...	·40	29·800	66·060	45·1	38·5	107·414	8·50	24·8	Ditto.
1,359	Ditto ...	·50	29·400	65·830	44·6	44·5	118·612	8·66	26·4	Ditto.
1,365	Ditto ...	·62	26·300	61·810	42·5	43·3	109·180	13·80	25·5	Ditto.
1,373	Ditto ...	·70	24·500	60·080	40·7	45·5	110·238	17·72	25·0	
	Mean ...	...	28·783	64·618	44·4	43·2	114·054	10·79	24·6	Silky.
Crossway.										
1,342	Unannealed ...	·37	34·300	72·670	47·2	37·5	116·397	4·52	22·4	Silky.
1,372	Ditto ...	·71	30·400	67·340	45·1	43·6	119·528	7·07	24·7	Ditto.
	Mean ...		32·350	70·005	46·1	40·5	117·962	5·79	23·5	Silky.
1,344	Annealed ...	·37	31·200	66·880	46·6	46·6	125·294	9·39	26·4	Silky.
1,348	Ditto ...	·40	31·000	66·920	46·3	49·6	132·843	9·07	26·3	Ditto.
1,354	Ditto ...	·42	30·000	65·780	45·6	39·0	107·920	7·81	20·4	Ditto.
1,360	Ditto ...	·52	29·800	66·540	44·8	46·7	124·912	8·50	20·2	Ditto.
1,366	Ditto ...	·62	26·300	60·570	43·4	35·3	93·649	16·61	22·7	Ditto.
1,374	Ditto ...	·70	24·500	60·220	40·6	50·7	122·185	17·30	26·0	Ditto.
	Mean ...	...	28·800	64·485	44·5	44·9	117·800	11·44	23·6	Silky.

Therefore, taking the lowest tensile strength of Best Best iron and of Landore steel, there is a difference in favour of the latter of 10·20 tons, or the Landore steel is 56·6 per cent. stronger than the Best Best iron. To show that this increased strength is not obtained at the expense of ductility, I may state that the elongation in 8 inches

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was in the test done at Landore lengthwise 29·6 per cent., and crosswise 23·4 per cent. I am not able to compare these with results of similar tests in Best Best iron, as these were not stated.

Another point to which I would direct your attention—and, I believe, I am correct in stating that it is one to which you will attach very great importance—is the effect produced on the Landore steel by punching, as compared with the effect on Bessemer steel, or on iron.

Referring again to Mr. Barnaby's Paper, I find that he states that Bessemer steel, commencing with a tensile strength of 33 tons to the square inch, gave on an average of six experiments only half the strength after being punched. Experiments in this direction conducted at Pembroke Dockyard with Landore steel show that the reduction in strength after punching was very small indeed, the breaking-strain being on three specimens—26·97, 27·0, and 27·01 tons on the square inch respectively. In a series of experiments conducted at Landore, which I regret I was not able for want of time, and in consequence of the failure of the machine, to carry further, the following results were obtained:—

From a plate which gave a tensile strength of 30 tons a number of test pieces were prepared; these had pieces punched out of their edges, midway on their lengths, equal to half a hole for a $\frac{3}{4}$-inch rivet; this was done in some cases to plates which had been annealed, whilst in others the plates were unannealed; again, some were annealed after punching, while others were not, and yet the limits of variation are between a minimum of 29·33 tons, and a maximum of 33·01 tons tensile strength, or only 11 per cent., while the extension far surpasses that of the Bessemer steel, and nearly equals that of the iron supplied by Mr. Crampton which Mr. Barnaby quoted. These are shown in the following Table:—

	Area per Square Inch.	Breaking Load per Square Inch.	Elongation in 6 Inches.	Per Centage of Elongation.
		Tons.	Inches.	
Plate Unannealed, both before and after Punching ...	·750	29·33	$\frac{3}{16}$	3·1
Ditto ditto	·710	30·94	$\frac{1}{4}$	4·1
Plate Annealed only after Punching	·703	30·08	$\frac{7}{16}$	7·2
Ditto ditto	·742	33·01	$\frac{9}{16}$	9·3
Plate only Annealed before being Punched ...	·687	32·02	$\frac{1}{4}$	4·1
Ditto ditto	·750	30·06	$\frac{7}{16}$	7·2
Plate Annealed both before and after being Punched	·726	31·68	$\frac{1}{2}$	8·3
Ditto ditto	·703	30·08	$\frac{7}{16}$	7·2

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The chief objection to the use of steel appears to have been the uncertainty as to its character. Doubtless, there have been Bessemer steel plates supplied for boiler-making, which have been all that could be wished, but there has always been the possibility almost amounting to probability, that along with a lot of good plates there might be delivered and used one or more plates unsuitable to the purpose intended, which would have the effect of counteracting the good resulting from the use of the good plates, and of converting a good serviceable job into an utterly untrustworthy one. Now, I venture to submit that there need not be the "fear and trembling" in the use of Landore steel, which is universally felt in regard to Bessemer steel, and which Mr. Barnaby so graphically described,—and for this reason, that nearly absolute uniformity in composition and quality may be depended upon, seeing that during the process of manufacture test samples are continually taken and analysed, with the view that the product shall have a certain definite carburization, while large quantities are dealt with in each charge. The uniformity of the metal put into plates would thus appear to be a matter of certainty.

I think I have also shown that the material can be readily manipulated, and that too with comparative ease: the Hot and Cold Forge Tests which I have had the privilege of placing before you would seem to be sufficient evidence as to this fact; but I am able to add to this testimony that of the Chief Constructor (Mr. Martin) and other officials at Pembroke Dockyard, who state that they have now pretty well overcome any difficulties they have laboured under in working the steel, more especially that of welding, which I am informed is now satisfactorily accomplished. It is further stated that they find that in punching the holes in the 6 inch by 3 inch by $\frac{7}{16}$-angle framings, after being bent to the required form, their shape does not alter more than half as much as angle iron when similarly treated; and again that the oxidation during the various processes is so small, and the surfaces of the plates remain so good and smooth, that not half the labour is required in scraping, cleaning, and painting after they are fixed in their places.

In further proof of the utility of this material I am able to quote the following Table of Tests applied to rivets made from Landore steel, as compared with rivets of best Staffordshire iron, in which the superiority of the steel is again made manifest.

[TABLE.

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5th February, 1876.

Tensile Tests of Landore Rivet Steel—Shearing Tests of Steel and Iron Rivets.

No. of Test.	Description of Material in Plates.	Thickness of Plate.	Description of Material in Rivets.	Description of Rivets.	Description of Rivet Head.	No. of Rivets.	Actual Shearing Strain.	Actual Shearing Strain for each Rivet.
		Inch.		Inch.			Tons.	Tons.
1	Landore Steel	½	Landore Steel	¾	Snap	4	56	14
2	Ditto ...	„	Ditto ...	„	Pan	„	56·14	14·03
3	Ditto ...	„	Ditto ...	„	Countersunk ...	„	59·56	14·89
4	Ditto ...	„	Staffordshire Iron	„	Snap	„	41·12	10·28
5	Ditto ...	„	Ditto ...	„	Pan	„	40·78	10·19
6	Ditto ...	„	Ditto ...	„	Countersunk ...	„	45·22	11·3
7	Ditto ...	„	Landore Steel	⅝	Snap	„	37·36	9·34
8	Ditto ...	„	Ditto ...	„	Pan	„	37·36	9·34
9	Ditto ...	„	Ditto ...	„	Countersunk ...	„	43·85	10·96
10	Ditto ...	„	Staffordshire Iron	„	Snap	„	29·84	7·46
11	Ditto ...	„	Ditto ...	„	Pan	„	31·8	7·95
12	Ditto ...	„	Ditto ...	„	Countersunk ...	„	34·29	8·57

(*Note appended.*)

Forge Tests of Landore Rivet Steel.

I beg to say that we have tried the samples of ¾-inch and ⅝-inch round steel in making rivets, in riveting plates together for tests and the tensile tests, and we find that it works sound and well, and that rivets can be made of the steel with the same facility as of iron. Also we drew the points of each to a scarph, and bent round, and gave it a welding heat, which it stood fairly, sufficient to have made an eye-bolt if required. I am of opinion from those trials that it is very good rivet steel.

It thus appears to me that this metal meets in a larger degree than either iron or ordinary soft steel all the demands of naval architects, seeing—

(*a.*) That it has nearly the same strength in both directions of the plate, and that that is much greater than that of iron.

(*b.*) That its ductility is equal to that of iron, and greatly superior to that of ordinary steel plates.

(*c.*) That the resistance offered to impact, as shown in the percussion tests quoted, as well as in the specimens which have been submitted to the bulging and gun-cotton experiments, is superior to that of plates from either, say, good iron or ordinary steel.

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(*d.*) That the "tempering," and consequent diminution of strength produced by shearing or punching is not as great as is the case with either iron or ordinary steel.

(*e.*) That the surfaces of the plates being much smoother, the friction and consequent loss of power or speed in vessels built of this steel must be less than in the case of iron vessels.

(*f.*) That the superiority in strength of the plates made at Landore over iron being so great, one of two results must happen in the case of vessels in whose construction these plates are used. Either they will be very greatly superior to iron vessels in strength, or their strength being reduced to that of iron their weight must be equally reduced, and their carrying capacity very largely increased. The importance of this consideration will be understood and appreciated without my urging it upon you.

There is also another quality claimed for this steel, which, if substantiated in actual experience, will prove to be of very great importance. I was recently informed by M. Gautier that a series of experiments, extending over about three years, and carefully conducted at the Terre Noire Works, had established the fact that, when exposed to the action of sea water, this soft steel suffered by corrosion only in the proportion of 60 to 140 when compared with the effect of similar treatment upon iron plates. I do not vouch for the accuracy of this statement, but simply quote what was related to me as a fact; its importance, however, you will doubtless appreciate.

All these considerations force upon me the conclusion that only a short time must elapse before the value of this material being more and more recognised, it will replace iron, not only in the construction of the hull of the vessel, but that in the form of wire, forgings, and in other ways as well as plates, it will be used in the building of the vessel, the masts, and rigging, in the construction of the machinery, and I was going to add, and I think I may with safety do so, in the armour-plating used for its protection. If these things are accomplished something will have been done towards answering the challenge Mr. Barnaby made, and also in the maintenance of our position as steel manufacturers when compared with those of other countries.

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DISCUSSION.

Rear-Admiral WILLIAM HOUSTON STEWART, C.B.: My Lord, being the responsible officer through whom the steel, on which we have heard this interesting Paper, was recommended for adoption by the Admiralty, I desire to point out one quality which I think will demonstrate itself to the minds, at any rate, of naval officers who study, or have considered, the deadly effect of shot and shell on unarmoured ships as at present constructed, either of wood or of iron. The result of the recent experiments conducted at Shoeburyness point out, that for the purposes of war, and for actual combat in time of war—however useful they may be for naval purposes in time of peace—unarmoured vessels are practically useless. Perhaps Mr. Riley will point out to us whether the same effects may be expected from that steel when struck by shot or shell as is shown in the experiments carried out at Pembroke. I mean as to the probability of limiting the deadly effect of splinters; and I think that that was one of the important points that we had in our minds in recommending the adoption of that material for use in vessels of war. During a visit to the French Dockyard, at L'Orient, I was informed that experiments had been made on two targets, representing sections of unarmoured ships; one was made of the material that had hitherto been used in the French Navy, the other was made of the steel that was then being adopted in the construction of the *Redoutable* and other ships in France; and the result of those experiments completely surprised the artillery officers. The steel target when struck showed a wonderful absence of splinters. They had predicted that the same effect would be produced on the steel target as had hitherto been produced on the iron target; that is to say, that, from the amount of splinters, and I may say from the murderous effect in the neighbourhood of the space that would be occupied by the gun's crew, it would be impracticable for men to live at their guns under the fire of shot or shell. That is the experience recently gained by the experiments at Shoeburyness. When I tell you, that with a gun's crew of fourteen or sixteen men, standing at a gun, the effect of one shell has been to blow away the whole of the men on one side of the gun, and to kill three or four men on the other side, and to totally destroy the gun's crew on the opposite side of the deck, it becomes a matter of consideration how these combats between two unarmoured ships, if constructed with ordinary iron—and the effect with wood or composite material is even worse—can possibly be carried out. I had the pleasure of paying a visit to the establishment of Dr. Siemens, and of seeing the process by which this steel is prepared; but I had not the pleasure of meeting Mr. Riley there. I have always wished to have the opportunity of asking him, whether, when this material encounters the application of projectiles, the same favourable and satisfactory results may be expected. He has alluded to the possible application of it for armour-plates, and it appears to me that an armour-plate, which would combine these qualities that we see there, and lightness, by which it might be used for the protection of cruising vessels, would be an exceedingly valuable point for us to arrive at.

Admiral the Right Hon. the EARL OF LAUDERDALE, K.C.B.: I think I have heard in this room, when we were upon the question of iron plates or steel plates before, Mr. Barnaby objecting to steel, inasmuch as there was an uncertainty in the manufacture of it, for making plates either for armour or for boilers. I suppose he alluded to Bessemer steel; but I would ask, whether, in the manufacture of this steel, there is any certainty, such as there is in rolled iron, of its being of the same quality always. What Admiral Stewart has pointed out is a matter of the greatest consequence. If it will not stand shot

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it is useless for the purposes of war; but I have always understood that the great objection to steel for ships' purposes was the uncertainty in the manufacture. I think it is stated here that some of the plates of the Bessemer steel, upon trial, were found good, and others, again, were found perfectly useless; so that the question of adopting it in the Navy for the purposes of shipbuilding—and particularly for the reason that Admiral Stewart has mentioned—I think is a point that requires very great consideration.*

Mr. NATHANIEL BARNABY, C.B.: I think his Lordship has not quite gathered all Admiral Stewart meant to say with regard to the effect of projectiles upon the steel, because he knows that in the target experiments to which he is referring at Shoeburyness, the steel of which one side of the target had been made is reported by the officers who made the trial to have stood better than the iron. Therefore there is, with regard to the Bolton steel of which that target was made, the evidence of those officers that that steel stood the effect of the projectiles better than the best iron. But, then, that was not Siemens steel; and he will say, "If it was Bessemer steel, why did you, last year, say that Bessemer steel was not to be "trusted?" That is a very proper question, and I proceed to give the answer. The answer is this:—Admiral Stewart and I saw, in France, a material, which—as he has described to you—stood the attack of the guns upon it in a manner which surprised the French officers; and I had never seen, in England, steel so mild, or which seemed to me to be so well fitted for shipbuilding purposes as I saw there. It had been made, part of it by the Siemens process, part of it by the Bessemer process; and when I read my Paper, last year, having seen that material, I threw out the challenge, that Mr. Riley has referred to this morning, to the steel makers of England; and I told them, what I say now was true, that they had not given to the shipbuilder and to the marine engineer such material as we saw in France. I will say now, further, that after that Paper had been read, and communications had been made to the first Bessemer steel makers in England, they told us they could not comply with the conditions; they never had made, and did not believe anybody else had made, Bessemer steel which would be uniform less than 30 tons per square inch; and that was the condition which we supposed, and the French officers supposed, was necessary in order to get the mildness which we wanted. But since that time steel has been made by the Bessemer process as good, as far as I can see; and we have a contract with the Bolton Steel Company, running on with that with the Landore Siemens Company, for steel which is apparently as good as that made by the Siemens process. In referring to the target at Shoeburyness, I told you that the steel used there was made by the Bolton Steel Company. I believe that if we had had, side by side with it, the Landore steel, made by a different process, we should have found that we had, in both cases, a splendid material, such as shipbuilders might use with a very great deal of confidence. My remarks, last year, were taken somewhat unkindly, as I thought, by the Bessemer steel makers; and I would ask the gentlemen in the room now, who know most about the matter, whether we have not, since last year, got a material better suited for shipbuilding than we had then seen.

Mr. CHARLES W. SIEMENS, F.R.S., D.C.L.: Following up the observations made by Lord Lauderdale and Mr. Barnaby, I may, perhaps, be allowed to say a few words with regard to the reason

* LORD LAUDERDALE in the course of the Meeting subsequently said: "I made a remark when the Paper on Steel "Plates was read, and I am afraid I misunderstood what Admiral Stewart said. I understood him to say that, in the "experiments at Shoeburyness, the plates had so splintered that they showed they would kill all the men at the guns with "splinters. He has told me that I misunderstood him, and that he said it did not splinter at all. Therefore what I should "have said was quite the contrary—that the steel plates are applicable for war purposes, and better than the iron plates. "I said they were unsuited."

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there is for expecting a more uniform result from the process as carried on at Landore, and at other works, in my open-hearth furnaces, than what can be reasonably expected by the Bessemer process, or by the old Sheffield process of melting steel in pots. There can be no doubt but that very excellent steel can be produced by the Bessemer process, if all the conditions are favourable; but this process is dependent upon the close attention which has to be paid by the attendants during the action of the blow, and in the after process; whereas the open-hearth process has this peculiar advantage over, I may say, all other processes for the production of steel, that the metal is in an open bath—10 tons of melted material—and there is no hurry about it. We are not limited to a blow of ten minutes or a quarter of an hour, but the steel-melter, like the *chef de cuisine* in a French restaurant, takes his sample out, not to taste, but to test, and if that sample is exactly to his satisfaction, he pours it out into moulds in the usual way. There is one other point which is of importance. It may be said that the quality of steel depends upon the materials of which it is composed, and on their purity. That is very true, but not altogether true. In chemical combinations we have either a simple aggregation or further chemical compounds, and we know that carbon, for instance, exists in two distinct forms in combination with iron. Then we know that molten steel absorbs oxygen from the atmosphere in very large proportions, and unless the process admits of this oxygen being removed before the metal is poured, it must necessarily influence the quality of the steel when finally produced. It is with regard to these points that the open-hearth process presents very considerable advantages—advantages which have been sufficiently dwelt upon in the Paper itself to render it unnecessary for me to add anything, or to occupy the Meeting further.

Mr. J. I. Thornycroft, C.E.: I would beg to make a few remarks on steel, and would like to speak of it mechanically in contradistinction to Dr. Siemens, who has given us various chemical analyses. Mr. Barnaby has spoken of limiting the strength of steel to about 28 tons, and seems to consider steel of greater strength than that cannot be relied on as thoroughly trustworthy material. I would beg to differ slightly from Mr. Barnaby, on the ground that I think the extension of steel is a quality indicating really its trustworthy character; and Sir Joseph Whitworth, at Manchester, showed us a specimen of steel which would extend about one-third, and had a tensile strength much over 30 tons—I believe approaching 40 tons. And at Crewe, through the kindness of Mr. Webb, I saw steel being tested—I am not quite certain about the tensile strength of it, but the extension was very great indeed. It was plate made for boiler making, and there were two marks made upon the test pieces which had about a $\frac{1}{2}$-inch section, two inches apart. The specimens, before breaking, elongated to about $2\frac{7}{8}$ths, thus giving an apparent extension of about 50 per cent. This amount of extension was very uniform in a number of experiments. I think there is a great want of uniformity in this way of testing among different engineers, and a great deal must depend on the length of the piece which is stretched, and I think if some uniform scale of comparison could be agreed to, it would be a great advantage, and would enable us to judge better of the comparative merits of steel for extension. The principal thing I wished to draw attention to was, that the Bessemer steel is produced of higher strength than is assigned to this material, and possessing so much power of extension; I consider it must therefore be a trustworthy material. What appears to me to be the fact is, that if there exists in a structure a crack so as to greatly diminish the section at one particular point, when that structure is put in stress or extended, without the material can extend very greatly, that crack will immediately, by the great stress put on the reduced section exactly at the end where the structure ceases to be continuous, go right across, and break with very small force indeed. I must say, although I have very great faith in Bessemer steel, and believe that it can be very satisfactorily produced; yet that which

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Dr. Siemens said is very true, that being enabled to "cook his steel to his mind, and to stop and test it at "any time," is of very great importance, and leads us to have great confidence in the material which we have had brought before us to-day.

Mr. BENJAMIN MARTELL: The Paper which we have had read before us to-day will I am sure be highly satisfactory to all those who feel an interest in the business of shipbuilding. I think, remembering the Paper that was read last Session by Mr. Barnaby and the Discussion held on it, that we have made great progress since that time, and that we really appear now to have arrived at a point where we have a material such as we can use with confidence for shipbuilding purposes. The great want of uniformity in the quality of steel, added to the great alteration in its quality after being punched and sheared and submitted to blows which required it to be annealed, to bring back its original temper, were the main causes of such material not being encouraged for the purpose of mercantile ships. I think it is a very important point in the material we have heard described, that we can not only obtain uniformity, but that there is also the very great advantage of the temper not being materially affected by the punching and the shearing, because if all these plates required annealing after being punched and sheared, although this could be done in building a Government ship, where there is plenty of supervision and officers, yet in a mercantile yard it is perfectly impossible to obtain it; and no matter how good the quality of material may be, if all the plates had to be annealed after being punched, we could not feel confidence in its use for mercantile shipbuilding. We have in this Landore steel as far as I can judge a material fitted for use in ships, and that can apparently be relied upon; and the great question now is, what is the difference of cost, compared with good iron, and what reduction can you make in the weight? We cannot expect, if this is very much more expensive than ordinary iron, its general adoption; and as to the amount of reduction we can make in the scantlings on account of it, that is a matter which will require serious consideration. I think it would be of very great interest if Mr. Barnaby could tell us about what per centage of reduction in the ordinary sizes of material has been allowed in the steel vessels that are being built, because that would assist us in forming an opinion upon that which is an essential consideration with regard to the use of this material for the building of merchant ships. I should say, with reference to what has been said about high tensile strength of steel being combined with ductility, that we have seen a great many experiments with steel of various kinds, and have not found the two qualities combined. Some steel even in passing from the forge, if a current of cold air passes over it, becomes altered in temper very considerably indeed, and such a sensitive material is not fit for building of merchant ships. The Committee of Lloyd's Register, when ships to be built of good ductile steel are brought forward with a view to classification, allow a reduction of about one-fifth in the scantlings; and when we see that this material stands a tensile strain of only about 28 tons (I believe in order to get ductility you cannot go much beyond 30 tons), it becomes a question whether any greater reduction can be made in the scantlings, because there is a great deal of good iron which will stand within a fifth of this tensile strain. Still we have in this material a good homogeneous metal that can be relied on for uniformity and which will be more satisfactory, no doubt, than ordinary iron; and even if it is not used generally, and cannot be used on account of its cost for the hulls of ships, there is no doubt that it will be of very great importance indeed in the building of masts, and in the rigging, where strength and lightness combined are the two great essential requirements. I believe if such a material as this can be produced at a reasonable cost it will be very considerably adopted for the building of mercantile ships.

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Mr. CRAMPTON: I think the last speaker is not quite aware of the improvements made during the last twelve months. My impression is, that those changes in the temperature which he refers to in passing over the hot plates, which he said produced bad results, have no longer that bad effect, and that actually the steel can be made red hot and hardened in cold water without hardly any effect being produced on the tensile strength,—in fact so little, that it will bend over cold. If that point is arrived at, I think you may throw your hot plates on the cold ground, when you are bending them, without much fear. But there is one thing which he mentioned which is perhaps of importance for the moment, and that is the cost. To my mind this homogeneous metal, or steel, or whatever you may call it, will take its proper place, and must oust the bad iron now used in ships. But up to a certain time iron will be used to a very great extent, because it can be made very much cheaper. I presume that the material we are speaking of here cannot be produced or sold for less than £18 or £20 a ton. The merchant navy will not like to pay that price for their plates,—and the question is, what is to be done? The merchant navy have no right to use some of the material they do, because a great deal of it is simply like so much cast iron. I have seen such plates break on touching the ground when accidentally dropped from trucks. If you have a bad material, and it is carelessly put together, you never can depend upon it, and the process of manufacture is such that it is unreliable. Common iron plates were produced that would sometimes stand 25 tons to 28 tons per square inch, but which the slightest blow would break. Can you expect to produce a material which will be equal in all cases, if it is made up of laminated pieces depending on the welding for their homogeneity? I think it is an impossibility, and in the presence of my many friends here who have a great deal to do with welding, I make the statement. It never has been done practically. Occasionally you may produce it, but if you will plane the surface of any iron plate down the 16th of an inch, a 16th more, and a 16th more, you will find that the very best laminated plates ever made under the best conditions are not perfect. But if you take a homogeneous iron plate and plane that down, you will find that it is better if anything inside than outside. Another advantage of having the metal in a mass of equal quality is this, that practically you have the same strength both ways across and with the grain—of course they are not so strong as those steel plates to which Mr. Barnaby referred last year. We made homogeneous iron plates from the commonest pig iron known, and produced better results in one respect even than those which are shown in the experiments referred to in the Paper—that is to say, we injured the plates less in punching. The plates were only deteriorated 5 per cent. when punched, whereas 50 per cent. was lost in the hard Bessemer; and with regard to the other great makers, their plates were deteriorated from 25 or 30 per cent. by punching. But in the homogeneous steel plate the loss was still a little more than in a plate of mine, which was also referred to by Mr. Barnaby. There is a reason for that. The bloom is made in one mass, and it is rolled out evenly, and it is softer than the steel plate, that is to say, we could stretch it to a greater extent, and we have stretched it up to 35 per cent. or 40 per cent. It is softer altogether, and the result is, it being homogeneous as well, the particles are not disturbed so much in punching as if it were harder. Now, I come to the main point. My impression is, that what we are doing now must change the whole manufacture of iron plates. Manufacturers may object as much as they please, but they must give up making plates from piles, the public will not have them, and nothing can show the value of it so much as these experiments. My experiments were of a more limited extent than these, which extend over a considerable time, yet they were extensive, and have proved beyond a doubt that the homogeneous iron plate is far superior to any piled-up plate ever made, and I have no hesitation in saying that homogeneous plates can be made of

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common Cleveland iron, which ought not to cost at this moment at the works more than £7 a ton, and which will stand all tests of steel except that of possessing the strength that you see there. Do not misunderstand me, not in strength, but in ductility, in stretching qualities in every form. These are of a quality suitable for general purposes, and for those users who cannot afford to pay £20 per ton. I see my friend Mr. Bramwell smiles; I think he knows pretty well these will not cost more than £7 a ton. The soft steel plate will stand 20 per cent. greater tensile strain than my soft iron plate, but would cost at least double.

Admiral SELWYN: I would ask Lord Hampton's permission to draw attention to two experiments in this Paper which are of the utmost value, and will have increasing value as we go on; they are Nos. 20 and 21, in which gun-cotton was used. It is quite clear that the question of proving a plate by punching it is one of velocity. Given the velocity of the punch, then we can tell whether perforation will take place with mere drawing of the metal, or whether the tenacity of the metal being overcome by the velocity, pieces will be taken out. By no possibility with punches could we manage to do that, because it would require an immense deal of calculation and there would be a great liability to error, whereas the gun-cotton gives us at once a velocity superior to that of any shot, and gives us an answer to the question as to whether punching will take place, and that kind of breaking up during punching which occasions the danger of splinters flying from the plate, and which appears not to be the case in the two experiments with gun-cotton which have been mentioned. We are not told how that piece was disposed of, but the Paper states that a hole 1½ inches in diameter is made in the centre of the plate, and that for three quarters of an inch all round this hole the plate is beautifully countersunk as if it had been done by a tool. There are no lateral fractures in the plate. I think it is a matter of the utmost importance in a question of the resistance of the plate, and it is an experiment which is so easily made and so much within any shipbuilder's power to make, whereas he could not resort to shot in most instances to know how his plates would resist, that it may be very well worth pursuing even for the merchant shipping, but it is of still greater importance to the Navy. In our ships we seem to have arrived at a point where we must either consent to confine our plating entirely to the armour belt, or to carry insufficient armour which can be pierced above that line, exposing the batteries to a serious danger. If we can eliminate any portion of that danger in this way it will be of the utmost importance, and will enable us to carry guns on decks, the sides of which otherwise being entirely permeable to shot of whatever nature, and being then driven into splinters, would be even worse than shell fire.

Mr. JOHN CORRY: A previous speaker seemed to insinuate because iron plates were laminated that therefore they were not to be depended upon. I certainly think he tried to prove too much. We know that very good iron can be made, and that some bad iron no doubt is made. I think the insinuation he threw out with regard to the iron used in the merchant service as being little better than cast metal is not altogether correct. I think it is quite the exception—it is not the rule. Of course for special purposes, such as Government purposes, and where shot and shell have to be contended with, you require the very best possible material that can be made with all the best qualities, but I think for ordinary shipbuilding purposes good iron has hitherto answered the purpose very well it is merely a question of price. If this material, which no doubt is of a superior quality, could be made at a reasonable price it would be adopted. As Mr. Martell has suggested, there are special places in a ship where weight is of importance, as the masts, rigging and yards, and so on,—where the cost of the material does not come into question,

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because the saving in top weight is of more importance than the cost of material. It is purely a question of cost as far as the mercantile marine is concerned.

Colonel CLAY: I had the honour of reading a Paper in this room fifteen years ago "On the "Manufacture of Steel." I should like to say a few words with regard to that manufacture as it has been carried on very largely since. I have myself made many thousands of tons of that material. I refer to the manufacture of puddled steel or wrought steel—a steel which has the tenacity and the fibre of iron combined with the strength of steel. The material has been made of all shapes and forms, and it seems to have the advantage over this material that it is easily welded. It has been made not only in the form of plates, angles, beams, and all forms requisite for shipbuilding, but it has also been used for forgings of the largest size which have done their duty in a remarkable manner. Several steam-ship companies have used them almost exclusively and in large numbers, As far as my experience goes it has only had one bad quality, and that is that it is rather expensive to manufacture; and some of the companies have declined to go to the extra expense on that account; but some of our larger steam-ship companies are using it now. I believe the Cunard Company of Liverpool are using it for their screw shafts almost exclusively. I may mention also the North German Lloyd's, who have had it to replace cast-steel shafts made by Krupp, and also the Peninsular and Oriental Company. I will instance a vessel of theirs called the *Jeddo*, which after breaking many iron shafts had a cast-steel shaft supplied, which also failed; and then a puddled-steel shaft was supplied, which lasted the life of the ship and went down in the Red Sea with her at last. I would ask Dr. Siemens, really whether he thinks with further improvement, or in this stage, large masses of this homogeneous metal can be welded in pieces for forging such things as stern-posts and sterns, crank shafts, and other very ugly pieces of wrought iron that have to be made in large masses. I am reminded by Mr. Crampton of another point, and that is that in material which is cast in one mass there is a serious defect often comes in the cooling from contraction. In very large forgings this has been the case to an enormous extent, and sometimes has to be got over by other means. I remember when we were making those two monster chambers—the mortars, which are now at Woolwich, 3 feet in diameter, we found a great difficulty from this contraction; and after they were made we found that there were fissures that you could put your hand into, going in for almost a foot. We afterwards got over that by partially boring in the first instance; but that difficulty, which is a great difficulty with regard to large masses of iron and steel, is much greater in cast steel, where you have a much higher temperature to obtain than where it has to cool from the melting point, which is much higher than the melting point of iron.

Mr. JAMES RILEY: With reference to the remarks of Admiral Stewart, I think I cannot do better than refer him to the specimen which is upon the table. I should imagine that the injury from the explosion of gun-cotton being so small, a corresponding result would be obtained when shot was fired at the plates. It has not fallen to my lot to have experience in that direction; but judging from that experiment I should say that a similar result to that found by the French officers would be found in the case of shot striking our plates.

The PRESIDENT: Was the plate supported by the anvil in that instance at all?

Mr. RILEY: Yes. With reference to the certainty of manufacture I do not know that I can add anything to what has been stated by Dr. Siemens and other gentlemen in the room, that we seem to have a practical certainty as to the uniformity of the metal to be produced. Hitherto out of 5,000 pieces

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of plate and angles made, not one has been condemned for not fulfilling the tests. That is I think a sufficient answer as to the uniformity of the material. Then another gentleman referred to steel of greater tensile strength and to some which he had seen at Crewe; but as he was good enough to acknowledge that the comparison was not under the same conditions, the force of his remark is considerably lessened; that is to say, when the extension was measured only on 2 inches instead of 8 inches—as I think is taken by Mr. Kirkaldy, and also the standard adopted by the Admiralty—there can be no comparison. I have no doubt, if that gentleman will give me his name, I can send him the measurement in 2 inches. Then another gentleman referred to the extension of iron and to its tensile strength. I must confess that I have not read any report of any iron which will bear a tensile strain equal to that of the steel before you, I referred to the finest specimens of puddled plate which I believe have yet been made—namely those manufactured at Borsig's works, which I believe are really very fine indeed; yet, if you will note the comparison, you will find that there is a difference of 5 or 6 tons on the inch between those plates and ours. As I stated you must take the lowest tensile strength, that is cross-ways of the plate, and then the difference in favour of ours when compared with the Best Best iron is about 56 per cent. I admit what Mr. Crampton stated, that we did not quite come up to his iron in the matter of elongation, and that as to ductility we are a little short of that; but if you will put against that the acknowledgment he made, that we surpassed him a great deal in the tensile strength with almost the ductility, I think we need not yet hide our heads. I took for comparison the homogeneous iron to which he has referred; Borsig's plates which are professedly made homogeneous, although not by the Crampton process but in huge masses, and this plate I took so that there might be a fair comparison between ours and the best iron produced. As to the matter of forging which Colonel Clay referred to, we have done lately a great deal in that direction and are doing more. In the first place we are making double-crank axles for locomotives and moderately large shafts for screws, and in that direction we are now doing a good deal. We have made a good many large forgings for vessels being built at Birkenhead. There is no doubt great difficulty in the way of dealing with large masses of molten material such as was referred to; there is a danger of piping, but with care this difficulty is got over. I have nothing more to say, except to thank you for the kind way in which you have received my observations.

The PRESIDENT: I am sure we must all express our thanks to Mr. Riley for the really very interesting subject which he has brought before us.

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ON THE NICOLAIEFF FLOATING AND DEPOSITING DOCK.

By LATIMER CLARK, Esq., C.E.

[Read at the Seventeenth Session of the Institution of Naval Architects, 7th April, 1876; the Right Hon. LORD HAMPTON, G.C.B., D.C.L., President, in the Chair.]

THE Floating Dock now being constructed for the Russian Government at Millwall by Messrs. Clark, Standfield & Co., presents such novelties in design that it has been thought a description of it, and of their system of depositing vessels on fixed platforms would prove of interest to the Institution of Naval Architects. This dock is designed for the purpose of raising the large circular iron-clads which have recently created such great interest in naval circles, and also for docking the ordinary iron-clads of the Russian Government.

The popoffka *Novgorod* already constructed has, it will be remembered, a diameter of 100 feet, and another circular iron-clad, the *Admiral Popoff*, has a diameter of 120 feet; and it has been stated that designs have been prepared for a third popoffka of 160 feet diameter, and there can be no doubt that even larger vessels than this will yet be designed. The largest dock entrances at present in existence do not exceed 100 feet, and it is believed that no entrance so wide as 120 feet has been hitherto proposed. It is evident that the enlargement of such entrances to a width sufficient to receive circular vessels of the size above mentioned would be a serious and perhaps impracticable undertaking—the want therefore of some method of docking such vessels was one of the most serious difficulties to be overcome in connection with the introduction of circular war vessels. Admiral Popoff had been long studying this important question, and in one of his visits to this country he became acquainted with Messrs. Clark & Standfield's Gridiron Stage Depositing Docks, and at once perceived their merits and their adaptability to the wants of the Russian Government. Plans were accordingly prepared under the supervision of Admiral Popoff, who made numerous modifications to meet the special requirements of his Government, and the dock was commenced in January this year.

* Received 5th April, 1876.

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Before describing the Nicolaieff Dock it may be well to give a general idea of the leading features of this kind of dock.

The Depositing Dock is quite unlike any other dock that has been proposed, inasmuch as it not only raises the vessels out of the water but when required deposits them high and dry on fixed stages of open pile work, where they can be cleaned or repaired at leisure. It can also readily be altered in its form so as to receive vessels of the ordinary type, or to dock circular iron-clads of whatever size.

The Depositing Dock in its general form is composed of a number of pontoons, either of square or circular section, which lie parallel to each other at fixed distances apart, and which range transversely to the length of the dock; each of these pontoons is permanently connected at one end to a longitudinal structure which forms the main side of the dock; the pontoons project outwards from the side of the dock in the same way as the fingers of the hand, so that the whole structure in plan resembles a comb. The pontoons, when the dock is lowered to receive a vessel, are submerged; but the side of the dock to which the pontoons are attached is never totally submerged, but is of sufficient depth to allow a freeboard of 6 or 7 feet when the pontoons are sunk beneath the bottom of the vessel. When the dock is raised the tops of the pontoons are well above water, and the side of the dock stands up some feet higher than the deck of the vessel which it supports.

Diagram 1 (Plate VIII.) shows the plan of the dock, A A A being the side of the dock and B B B the pontoons; and Diagram 2 shows an end elevation of the same floating upon the water with a vessel upon it.

Diagram 3 shows an elevation of the dock submerged with the outrigger attached ready to raise a vessel. It will be seen that this elevation resembles the letter **L**. It is obvious that such a form as this, *viz.:* a dock with only one side to it would be perfectly unstable when submerged, but the necessary stability is imparted to it by means of the outrigger arrangement shown in Diagrams 2 and 3. This outrigger consists of a broad flat pontoon divided into numerous compartments, and loaded with concrete ballast until it is half submerged. Its form gives it immense stability—it carries along its middle line a row of rigid upright columns, which project through the pontoon some distance above and below and are stiffened by struts. To the top and bottom of each column is hinged a pair of parallel bars or booms, C C Diagrams 2 and 3, which are also hinged at their opposite ends to the sides of the dock, as shown in the diagrams, so that the outrigger remains stationary while the dock is free to be raised and lowered vertically, being always retained in a horizontal position by the action of the parallel bars or booms; the movement is in fact exactly that of a parallel ruler.

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Each of the fingers or pontoons is usually divided into about six separate compartments by means of five transverse vertical bulkheads. The side of the dock to which the pontoons are attached is practically a long box girder divided by numerous bulkheads into large water-tight chambers. Its height may vary from 20 to 50 feet or more, its width from 10 to 15 feet, and its length be about equal to that of the longest vessel intended to be docked. The pontoons are about twice the length of the beam of the vessel to be raised, so as to be available for paddle steamers; their height may be from 10 to 20 feet according to the weight of the vessel, and their width from 7 to 15 feet.

In the Nicolaieff Dock now in course of construction the side is 280 feet long, 44 feet 6 inches high, and 12 feet broad; the pontoons are 72 feet long, 18 feet deep, and 15 feet broad, and the clear space between them is 5 feet.

The machinery for working the dock is carried in the chambers of the side; it consists of a number of powerful pumps worked by steam engines in the usual manner.

When it is necessary to submerge the dock the necessary valves are opened and the water admitted through pipes to the compartments of the pontoons; the dock is thus gradually lowered, its horizontal position being at all times maintained by its connection with the outrigger; the vessel is then floated over the pontoons, water is pumped out until the keel takes its bearing on the blocks, the bilge blocks are hauled into place by chains in the usual manner, and the vessel being firmly blocked and shored, the pumping is continued until the vessel is raised to its full height as shown in Diagram 2; the valves are then closed.

In this position it will be seen that the dock with the ship on it has very great stability quite independently of that afforded by the outrigger, the outrigger having in fact performed its functions—*viz.:* that of controlling the dock when submerged—is no longer of any service; and it might, should occasion demand, be entirely removed as shown in Diagram 4. It may be remarked that the dock in this condition is much narrower than any other form of dock, and it might with great facility be taken through any narrow entrance or channel; there is however no necessity to remove the outrigger for any other reason. While thus docked the vessel can be examined, painted and repaired as in any ordinary dock, or can be removed from place to place.

The great feature of this system is that this vessel can now be readily lowered on to a fixed staging along the shore, and there deposited high and dry as shown in Diagram 10, leaving the dock free to raise or lower another vessel, or any number of other vessels.

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This staging consists of a series of piles driven into the ground in rows parallel to each other, these rows standing at right angles to the shore, as shown in Diagrams 1 and 10. The rows of piles are capped by horizontal timbers which are exactly the same distance apart from centre to centre as the spaces between the pontoons are, so that if the width of the pontoons is 10 feet, the clear space between the piles is 12 feet, leaving 2 feet for clearance. The height of the vessel above the water is greater than the height of the staging, so that when the dock with the vessel on it is brought alongside the staging the pontoons can enter freely between the rows of piles, and the vessel is carried directly over the staging without touching it; the dock is now slightly lowered by admitting water into the pontoons until the vessel rests upon the keel blocks on the fixed staging; bilge blocks are now placed under the bilges, and the vessel being securely shored, the dock is lowered just clear of the vessel and drawn out from the staging, and is then of course ready to receive other vessels.

The lifting the vessel off the stages and lowering it into the water is simply the reverse of this process.

In considering the question of the stability of this dock during the process of submersion and raising, it is of vital importance to regard the dock as consisting of two very distinct portions, *viz.:* the side and the pontoons. It must be borne in mind that in this dock, as in all others, the side or sides take no part whatever in the raising or supporting of the vessel; on the contrary, their office is simply and purely to give stability during submersion. Instead of being of any assistance in raising the vessel, their own weight has to be raised and carried by the pontoons or dock-bottom, in addition to that of the vessel itself.

It might appear at first glance that in this dock the great bulk of the single side would have a tendency when submerged to rise and cause the dock to list on one side, —and this would really be the case if the water were to be pumped out of the side and not out of the pontoons; but it must be clearly understood that the lifting power is applied solely and wholly in the pontoons, and directly beneath the vessel. The pontoons are provided with a certain number of hermetically-sealed chambers, into which the water cannot enter, and these are sufficient at all times to give the pontoons a surplus of buoyancy, so that they can only be submerged by being forced down by the weight of the side; and when the dock has to be submerged water has to be pumped into the side to give sufficient weight to carry down the pontoons. Similarly, in raising the dock, the water is pumped only out of the pontoons, allowing that in the side to flow out by gravity. The lifting power is thus applied by the pontoons alone, and that directly under the vessel, and the dock has no tendency to turn either one way or the other. It

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is however necessary to apply some power to keep the dock horizontal in all states of submersion, and this is provided for by the outrigger and parallel booms before alluded to. This outrigger consists, as before stated, of a large flat rectangular pontoon entirely decked, and of the same length as the dock itself and of about two-thirds its width. It is connected with the dock by booms in the manner before described, acting like a parallel ruler, so that its horizontality is exactly the same as that of the dock, and any tendency of the dock to list to one side or the other must be accompanied by a similar movement of the outrigger to the same extent, necessitating the raising out of the water of one side of the outrigger and the submersion of the other. A very simple calculation shows that the force requisite to thus move the outrigger pontoon, through even a small angle, is enormous, amounting to several hundred tons; taking the Nicolaieff Dock in its worst position as regards stability, the force necessary to make a dock and vessel list through an angle of 3°, is equal to 2,776 foot tons, or to 2,776 tons acting on the vessel with a leverage of 1 foot. This is shown in Diagram 5. With an angle of 10° this righting-power would increase to 16,080 tons.

Although we have pointed out the great righting-power which the dock with its outrigger possesses, it is necessary to remark that with ordinary management not more than a ton or two of this power ought ever to be brought into action.

The valve engineer is provided with a spirit level, and as soon as the dock shows any tendency to list to one side or the other, or to rise at one end more than the other, he adjusts his valves or shuts off his pumps so as to bring the vessel immediately horizontal.

The water compartments of the dock are more than a hundred in number, and are connected with the pumps by means of separate pipes, which are all brought to the valve-house and are then divided into four groups, corresponding with the four quarters of the dock; every pipe has also its own valve. Each of these four groups is governed by a principal valve, and a glance at the spirit level at once enables the valve engineer to ascertain and to control the action of each group and compartment.

Although in docking ordinary vessels and depositing them on the stages it is not absolutely necessary to make use of cradles, it is obvious that they may be employed with advantage in many cases. These cradles may either be provided with side-shoring frames as in Diagram 4, or may consist only of a platform of longitudinal iron girders stiffened transversely, and provided with the usual keel and bilge blocks. In either case the cradle with the vessel upon it is lifted bodily and deposited on the staging, and again removed with it when the vessel is lowered into the water.

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At the particular spot where the vessel is raised, there must obviously be sufficient depth of water to allow the dock to be lowered sufficiently to receive the vessel over the blocking; but when the vessel is docked it requires only a depth of water somewhat less than the height of the pontoons, so that the whole may be floated into shallow water or wherever the staging is fixed. The staging may be of indefinite length so as to receive one vessel or twenty, and a staging of given length may equally accommodate three short vessels or two long ones without loss of space.

When there is a considerable rise and fall of tide, the operations are of course conducted at the time of high water, but where the water is at a fixed level, or only varies a few feet, the dock may be worked continuously.

The Nicolaieff Dock which is now in course of construction on the Thames, at the works of Messrs. Clark, Standfield & Co., Millwall, is in all respects in accordance with the description above given. It has however some peculiarities which were necessary to adapt it to the docking of both circular and ordinary iron-clads.

The whole length of the dock is 280 feet, and it is for special reasons made capable of being divided into three lengths, each provided with its outrigger and complete in itself.

Two of these lengths are 100 feet each, and the centre one 80 feet.

Any one of these parts can readily dock the other for purposes of cleaning and painting. The centre length is furnished with four pontoons, and the two outer lengths each accommodate five; each portion is provided with separate engine rooms, engines and pumps, and valves. Their height is 44 feet 6 inches, and their width 12 feet. The pontoons are 72 feet in length; they are all alike, but instead of being permanently fixed to the side of the dock they are made easily removable and are mutually interchangeable; they can also be connected end to end, so as to increase the width of the dock to any extent.

The arrangements are such that these connections can be readily made without the assistance of divers. The width of the pontoons is 15 feet, and their height 18 feet, so as to give them sufficient floating power to dock the heaviest iron-clads. They are each divided into six compartments by upright bulkheads, but the four central compartments are again divided by horizontal bulkheads into upper and lower chambers; the four upper chambers thus formed are hermetically closed, so that when all the other compartments are filled with water the pontoon alone will float perfectly level with its deck a little above water.

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The outrigger is also divisible into three portions as before stated. It is in this case composed of two pontoons firmly braced together by lattice work; each pontoon is 15 feet wide and 6 feet deep, separated by a space of 15 feet, the whole forming a structure 45 feet wide. The booms are 43 feet in length, and there are seventeen pairs—*viz.*: five to the centre and six to each of the end lengths. The whole is weighted with concrete ballast.

When the three portions of the dock are joined end to end, the dock is adapted for raising and depositing iron-clads of the ordinary form; but when the dock is arranged so as to form a dock with two sides, it is suited for receiving circular iron-clads up to 140 feet diameter. This important modification is due to the inventive genius of the experienced Russian naval engineer, Admiral Popoff.

Reverting now to the Depositing Dock generally, it may be well to observe that it is usually designed in two halves, each of which is capable of readily docking the other for purposes of cleaning, painting, &c., or of being used as a smaller but complete dock. Diagram 6 shows these two halves connected ready to receive a vessel of ordinary form. Diagrams 7 and 8 represent them connected for docking a circular iron-clad. Diagram 9 shows the dock with one side and its outrigger removed, preparatory to depositing the circular vessel on the staging.

The most important advantage of this form of dock is the great facility with which its size may be increased as often as the growing trade of the port may render it necessary. This is accomplished by simply adding a third section in the centre of the dock, which may be done without necessitating the alteration of the existing portion, and at an expense not exceeding that which would have been incurred in the first instance.

In common with other floating docks this form has the advantage of requiring no fixed foundations, of being easily removed from place to place, of being capable of transporting vessels over shallows, and of possessing great economy of working and first cost. It is of course vastly quicker in operation than an ordinary graving dock, inasmuch as in the latter case the whole space of the dock has to be pumped dry, while in the Depositing Dock only a weight of water equal to that of the vessel has to be raised, and that through a smaller height. In fact the Nicolaieff Dock is capable of raising a vessel of 4,000 tons in little more than an hour. One advantage this form of dock possesses to a greater extent than any other is the thorough exposure of the vessel to sun and wind, which is of considerable importance both in painting and repairs.

Another use of this form of dock is to transport railway trains across ferries from one side of a river or lake to the other. The complete railway train is run on to a cradle

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resting on the piles, and being perfectly secured therein is lifted away by a dock of this form provided with false bows, and fitted with propellers, and is then deposited on similar staging on the opposite shore. The advantages claimed for the dock may be thus summed up:—

1.—With one dock any number of vessels can be docked and deposited high and dry out of water on wooden platforms, in a convenient position for cleaning and repairs, along the waste sloping shores of a river or wet dock.

2.—The provision of an additional length of staging, at a comparatively nominal cost, is equivalent to the building of an additional dock.

3.—As the dock is used ordinarily for lifting vessels on and off the stages, it can be kept at all times ready to receive disabled or other vessels, which can be at once deposited on a stage and the dock left free for further use. In this respect it has a great advantage over all other descriptions of graving docks.

4.—A vessel can be placed upon the staging, cut in two, and lengthened by lifting one half further along the staging by means of the dock.

5.—Vessels can be conveniently built on these stages on an even keel and launched without the slightest strain, and without the risk and cost of launching, and without occupying the space required for the formation of ordinary shipways.

6.—Vessels, when on the dock or stages, are thoroughly exposed to the action of sun and wind, allowing paint to dry and harden rapidly, and affording great facility for examination and repairs.

7.—The dock, with or without a vessel, may be readily transported from place to place, for the purpose of raising or depositing vessels at different points.

8.—The dock will not, under any circumstances, sink, even if all its valves be intentionally left open.

9.—One half of the dock can be readily raised level upon the other half for the purpose of cleaning or repairs.

10.—By the use of air, which may be stored in some of the chambers under compression, a vessel may be raised, sighted, and lowered again in less than an hour.

11.—These docks, if constructed in the first instance too small for the requirements of trade, can be at any time enlarged to any extent at the same rate per ton as the original cost.

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12.—The docks are capable of receiving vessels of any size or length, or of a width too great to pass through ordinary dock gates; such, for example, as circular iron-clads of 100 or 150 feet diameter.

13.—Lastly, in point of price, this dock is without any rival.

This Paper cannot be well concluded without drawing attention to the unique advantage which this dock alone affords—*viz.:* that of allowing iron-clads, torpedo boats, and vessels of every form, to be laid up in ordinary on fixed stages instead of afloat; the economy of this proceeding, and the extension of life which would be thereby given to our Navy, will be obvious to all naval men. The durability of vessels laid up high and dry on the stages would be immensely increased, and at a few hours' notice a whole fleet might be lowered into the water.

DISCUSSION.

Mr. CHARLES LAMPORT: My Lord, I shall only occupy the attention of the Meeting for a minute or two, to express the very natural apprehension which any owner of a vessel would feel in confiding it to the care of the engineer who would have to raise it by that dock. When I look at Diagram 6, upon which a vessel appears to be lifted, I can count seventeen pontoons, every one of which ought to be, according to my notion of preventing anything like a strain or an unnatural twisting of the vessel, emptied precisely at the same time. Mr. Clark has evidently faced the difficulty by his application of a spirit level, so as to put under the control of the engineer the means to prevent this probable inequality. All I can say is, that I for one should not be willing to subject a vessel belonging to me, costing from perhaps £30,000 to £50,000, to the chance of an engineer's neglecting his duty while raising such a vessel. If at either end the pontoons were not equally emptied, it seems to me a vessel might receive a considerable twist; and if in the centre of the vessel the pontoons were not simultaneously emptied with those at the ends, the vessel might be subjected to a very severe strain, as if she had been caught by her two ends on two rocks, and thus have a tendency to break in the middle. I may be entirely wrong in this respect, but I have had something to do with raising vessels out of the water, and I can further appeal to the experience of most of the gentlemen present whether it is not an exceedingly delicate, and, in some respects, a dangerous operation to perform. I should not be so much afraid of the vessel tilting or overturning, because probably when she did so she would be still waterborne; and further because the centre of gravity would not easily be altered laterally owing to the outrigger, although the vessel looks in a very critical position. Still, the probable strain upon the vessel, from the mechanical difficulty of emptying seventeen pontoons simultaneously, would to my mind present an insuperable difficulty to such docks coming into common use.

Mr. FREDERICK J. BRAMWELL: This is a subject to which I have paid some attention. In 1853 I was in New York, and saw there the American Sectional Dock. That was a dock consisting of pontoons with side chambers, with floats to each pontoon, the position of the floats being regulated by means of

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racks and pinions. The dock was made up of a number of sections, and it was proposed to add to those as might be required according to the length of the ship. That dock was in use for very many years, and for anything I know it may be in use now. The objections urged against it (which were those suggested by the last speaker) appeared to me to be valid; one of those was the difficulty of properly supporting a vessel on such a dock. The last speaker has put it that the various pontoons (I am now speaking of a sectional dock, but I think my remarks are equally applicable to the dock now before us, as that consists of a number of pontoons), in order that the vessel may be properly lifted, should be equally emptied. I think that is not so, but even a more difficult thing than that is needed: you want the different pontoons variously emptied or filled—that is to say, you require them to be so adjusted as regards the water that the weight of any particular part of the vessel that is coming over any pontoon shall be borne by the flotation of that pontoon. That is extremely difficult. Imagine a vessel floating in the water, and that you could then cut her into as many slices as you have pontoons: what you want is to put her on the dock in such a manner as that when the vessel is cut up into slices, and she is borne by the various pontoons of the dock, not one of those slices should tend to move or be raised up or to be lowered more than another slice. That is an extremely difficult problem. I think I may say, in the case of a dry dock that was constructed many years ago at Blackwall, where hydraulic keel blocks were used, it was found that the vessel on being allowed to settle on those keel blocks, when the water was removed from around her took a new shape and in that shape was made tight, but when she was water-borne again she returned to her original shape and then ceased to be tight. This is a proof that that which is wanted is not an elastic dock but a rigid dock. I thought when it fell to my lot to design a dock that it was well to design it in sections, but that the sections should be coupled up by being attached to perfectly rigid side girders, so that when it was used it should be as rigid as those structures known as box docks. With a dock such as I have made, one is still enabled to take any section away without the aid of a diver, and to put it on the remainder for the purpose of repair. While I am upon that point I may mention that at Alexandria, where there is a box dock, the French commander of that dock has got a most ingenious arrangement—a barnacle of large size which extends underneath the dock from side to side, the ends of the barnacle standing up above the water; by that means the barnacle can be entered at the ends, and you can go along the whole way under the dock from side to side, and by successive shiftings of the barnacle can go from end to end, and thus see every portion of the bottom of the dock without any difficulty whatever, and without the aid of a diver, and also by that means see any defect there may be in the dock, and repair it. I was extremely struck with the great ingenuity of the parallel motion of the float outrigger (it appears to me to be a very happy idea), which enables Mr. Clark in the use of the dock, having only one side, to steady it in the water, to obtain great stability; and by the use of that and the separate section he is enabled to lift his vessel sideways. Still it is open to the objection pointed out by the last speaker, and I would ask whether after all it is as good as the method of shifting vessels endways which was proposed and I think is practised by the Americans when they use their box docks?

Mr. JOHN CORRY: I think a great deal of the objection of the last speaker is got over by the use of this grid, which may be made of any strength. You must look of course at the ship as a whole. The ship has a considerable amount of rigidity in herself, and does not require to be supported at every point but even if a portion is not supported the rigidity of the structure is sufficient, especially in iron ships. I think the design is an extremely ingenious one, and the use of the parallel motion is very beautiful

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indeed. I think if this grid were made perhaps somewhat stronger than it is according to the model the great objection to an inequality in the rising of the pontoons would be got over.

Mr. Latimer Clark, C.E.: The first speaker is of opinion that the pontoons ought to have some appliance by which they could either be emptied simultaneously, or as Mr. Bramwell I think more properly stated it, be emptied to different levels in proportion to the load they have to sustain. Either of those arrangements may be readily introduced. As a matter of fact, the Russian engineers (and I must bear very high testimony to their skill and cleverness) have preferred that the pontoons should be emptied simultaneously; that is to say, that the pumps should act uniformly on a number of pipes all acting together, so that if there is any difference of level in any one pontoon over another, that one gives out more water, and they all flow naturally to a level. The simplest combination of pipes, however, enables you to empty 4, 6 or 8 pontoons—your pipes are numbered and under control—you can empty any series of them you like, and that series being all connected to one pipe, they all remain level. The operation is perfectly easy. Designs have been prepared for the introduction of indicators. The system is slightly complex, but I will not detain you more than two minutes in making it intelligible to you. A small air-pump is worked by the engine, and that pump communicates with an air-chamber and a number of pipes, one of which is carried to the bottom of each chamber in every part of the dock. Each pipe is in connection with a barometric column of mercury, and the whole of the upper end of each of these columns of mercury has a pressure upon it. The consequence is, that when this pressure is applied the mercury falls in the column below its natural level to an extent dependent on the height of the column of water in the pontoon below, at which point the excess of the air escapes under pressure; and therefore you can have inside the room a series of these columns indicating the height of water in each pontoon. If you have all the pumps working uniformly, all the pontoons will have level water, and the whole of these columns of mercury will range level. If you prefer any other distribution of the lifting power, you have a series of levels showing you the floating power of each pontoon. One man can guide the whole, and since the operation of raising would probably extend to an hour, he has very ample leisure to put any strain or adjustment he thinks necessary on the dock. Mr. Bramwell spoke of the necessity of rigidity in the dock, and I must say in designing this dock that has been one of the points we very much wished to obtain. I myself am not an advocate of the flexible docks or pontoons; I think a rigid dock is a very desirable thing, and we have great rigidity secured in this dock by the peculiar details of the construction of the side—which is really a very large box girder—and of the pontoons themselves, which being thoroughly braced (although the details are not shown here) are excessively rigid forms of girder, much stronger than an ordinary railway bridge. Therefore the whole structure is extremely rigid, and I think would satisfy the requirements even of Mr. Bramwell. He alluded to the shifting of vessels endways on the American system. That system has been and still is in use. I do not think it necessary to detain the Meeting by pointing out some objections which there are to it, although the system is very pretty and ingenious. A vessel is brought in on a large pontoon, and hauled endways off that pontoon on to the land, and afterwards hauled back again. Referring again to the question of rigidity, the third speaker alluded to the use of the grid, and that of course gives—especially if it is supplied with the side-shoring frames which you see there—any amount of stability, because the shoring frames may be as rigid as the vessel itself. Therefore I think the requirements of rigidity and the power of adjusting the burden to the weight which supports it are both provided for in this dock.

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ON THE RATIO OF INDICATED TO EFFECTIVE HORSE-POWER AS ELUCIDATED BY MR. DENNY'S M.M. TRIALS AT VARIED SPEEDS.*

By W. Froude, Esq., M.A., F.R.S., Vice-President.

[Read at the Seventeenth Session of the Institution of Naval Architects, 7th April, 1876; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

Mr. Denny has taken the bold but well-considered step of discarding the conventional type of measured-mile trials which, as regards the speeds tried, have long been limited to full speed and half-boiler power. Mr. Denny now tries each of his ships at four or even at five speeds; and the result is that he obtains fair data for a complete curve of indicated horse-power from the lowest to the highest speeds; whereas with trials on the ordinary system we obtain merely two spots in the curve, and these at comparatively high speeds, the intermediate or lower portion of the curve being left uninvestigated.

No doubt the limited view of the proper range of the enquiry to which the trials are intended to supply an answer arose from the belief that resistance must be as the square of the speed, and horse-power as its cube; and this belief, incorporated into one or other of the well-known "constants," has survived more or less persistently in spite of attacks and misgivings, and has constituted a self-supported obstruction to new ideas. It is also true however that M.M. trials even as at present limited are costly experiments, and notions of economy have assisted to damp the ardour of those who have been on other grounds willing to become innovators. But no expenditure ostensibly encountered in the search for truth is really so uneconomical as that which, while it seems to furnish information, helps to support error and in fact "darkeneth counsel by words without knowledge;" and it is to Mr. Denny's honour that finding the so-called constants were invariably variable and inconsistent, he determined of himself to strike out a new line and find out by trial what is fact, instead of contenting himself with assuming what ought to be the relation between indicated horse-power and speed.

* Received 18th March, 1876.

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A very interesting Paper which he read in the Mechanical Section of the British Association at Bristol, illustrated by instructive diagrams which gave the results of trials conducted on his system, at once showed how fruitful a field of investigation he had opened up. And as he was on the point of trying a new ship from which he expected good results, he kindly promised to furnish me with her lines and with the report of the M.M. trials; and with the sanction of the Director of Naval Construction it was arranged that I should test the performance of a model of the ship with the Admiralty apparatus, so as at once to see what was the relation between the ship's nett resistance at all speeds and the power expended in overcoming it. The results of the investigation were unusually interesting and instructive.

On the one hand Mr. Denny's horse-power results when closely scrutinised were found at once to supply most important information on the subject of engine friction, and on the other they have helped to corroborate and further elucidate certain general conclusions on the subject of the expenditure of power in propulsion, which other less crucial tests had enabled me to arrive at approximately. The method of analysis to which I subjected the results is one which I have long adopted with advantage.

I have always felt that the system of reducing the results of steam trials to indicated horse-power, though no doubt furnishing a true expression in a commercial sense of the relative merits of the ship under trial, tended nevertheless to cloud the real significance of the record, viewed as suggestive of those specialities of form or condition which have really governed the ship's performance; not only because indicated horse-power includes in one large term the merits of the ship, the engine, and the propeller, but because the term into which it groups these items is complicated by the introduction of the speed factor, instead of representing them under their more elementary form of force simply. With this view, ever since I have entered into such investigations I have invariably converted the horse-power term to a force term by simply dividing it by a speed factor; and, as shaping the reduction into its most natural and apposite form, I have adopted as the divisor the speed of the propeller, expressed not by its revolutions nakedly but by its revolutions $\times$ its pitch—that is to say, the virtual travel of the force delivered by the propeller. The result thus obtained from the indicated horse-power I have termed "indicated thrust;" it is in fact the thrust which the propeller would be exerting if the force of the steam were employed wholly in creating thrust, instead of partly in overcoming friction, driving the air pump, and overcoming other collateral resistances. Indicated thrust is simply a constant multiple of the mean steam pressure on the piston; and if this were given in the records of the trials, indicated thrust is $\frac{\text{mean piston pressure} \times \text{total piston travel per revolution}}{\text{pitch of propeller}}$; when however (as is commonly

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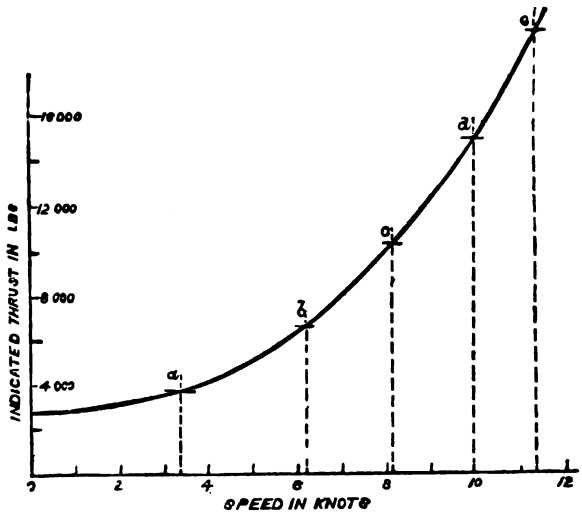
the case) the indicated horse-power alone is given, then the expression for indicated thrust is $\frac{33{,}000 \times \text{I.H.P.}}{\text{pitch} \times \text{revolutions.}}$

When decomposed into its constituent parts indicated thrust is resolved into several elements, which must be enumerated and kept in view.

These elements are: 1, the useful thrust or ship's true resistance; 2, the augment of resistance, which, as I have pointed out in many previous Papers, is due to the diminution which the action of the propeller creates in the pressure of the water against the stern end of the ship; 3, the equivalent of the friction of the screw blades in their edgeway motion through the water; 4, the equivalent of the friction due to the dead weight of the working parts, piston packings and the like, which constitute the initial or slow-speed friction of the engine; 5, the equivalent of friction of the engines due to the working load; 6, the equivalent of air pump and feed-pump duty.

It is probable that 2, 3, and 4 of the above list are all very nearly proportional to the useful thrust; 6 is probably nearly proportional to the square of the number of revolutions, and thus at least at the lower speeds approximately to the useful thrust; 5 probably remains constant at all speeds, and for convenience it may be regarded as constant though perhaps in strict truth it should be termed "initial friction." If then we could separate the quasi-constant friction from the indicated thrust throughout, the remainder would be approximately proportional to the ship's true resistance. In point of fact, the means of performing this separation have been furnished by the conversion of Mr. Denny's indicated horse-power record into a curve of indicated thrust. The determinations of the initial friction of the *Merkara*, the *Taupo*, the *Hawea*, and of the *Greyhound* appear in Figs. 1 and 2 (pp. 169 and 170) and Fig. 3 (Plate IX.) But the circumstance by which the separability of the initial friction from the other forces makes itself apparent, and the method by which the separation may be effected, will be more readily understood by referring to the accompanying hypothetical sketches rather than to the finished diagrams.

FIG. 1.



Assume that the ordinates at *a*, *b*, *c*, *d*, and *e*, Fig. 1, represent to scale the several indicated thrusts referred to the appropriate speeds; then a fair curve drawn through

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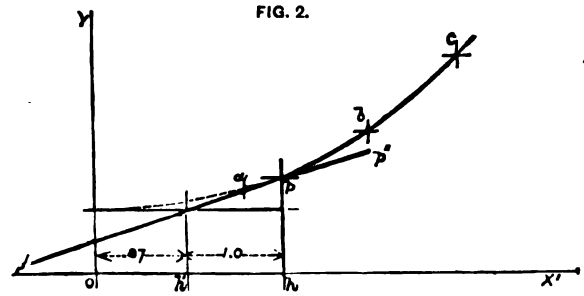
these points constitutes what I have called the "thrust curve." Now, on drawing the curve with the data supplied by Mr. Denny's trials, it becomes at once manifest in every case that at its low-speed end the curve refuses to descend to the thrust zero, but tends towards a point representing a considerable amount of thrust, and it is impossible to doubt that this apparent thrust at the zero of speed when there can be no real thrust is the equivalent of what I have termed initial friction; so that if we could determine correctly the point at which the curve, if prolonged to the speed zero, would intersect the axis O Y, Fig. 2, and if we were to draw a line through the intersection parallel to the base, the height which would be thus cut off from the thrust ordinates would represent the deduction to be made from them in respect of constant or initial friction, and the remainders of the ordinates between this new base and the curve would, as has been explained, be approximately proportional to the ship's true resistance.

FIG. 2.



Now the data do supply us with the means of fixing this intersection with considerable exactness in the following manner:—The curve as fixed by the data terminates at some moderate speed, say 3, 4, or 5 knots. It is well known now, that with tolerably well-shaped ships of such dimensions as those we are dealing with, the resistance due to such moderate speeds as these consists almost solely of surface friction, which—as our experiments have shown—varies nearly as the power 1·87 of the speed, with perhaps a very small residue or excess of resistance, apparently proportional to the square of the speed; and as this residue is very small indeed, we may without serious error assume that the whole resistance below 3 or 4 knots is as the power 1·87 of the speed. Hence on this assumption the lower end of the thrust curve when divested of the constant friction equivalent should be a parabola in which the ordinate is as the power 1·87 of the abscissa; and since, as we have seen, the entire thrust exclusive of the initial friction is proportionate at least at the slow speeds to the true resistance curve, the problem to be solved is the very simple geometrical one of so drawing a parabola of this order in connexion with the axis of co-ordinates of the diagram, that it shall meet or join the existing thrust curve with an identical tangential direction. The construction by which this is effected is extremely simple: at the point p, Fig. 2, near the lower end of the thrust curve draw the tangent $p' p''$; draw the vertical at h' so as to cut the space O h into segments having the ratio indicated by the figured quantities, thus making O h = 1·87 O h'; draw a line parallel to O X through the point where this vertical cuts the tangent; the point where this line cuts the thrust axis is the vertex of the required curve.

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The parabolic completions thus applied to Mr. Denny's thrust curves are found not only to meet them at a common tangent, but to "osculate" them for a considerable distance, which confirms the belief that the operation is not merely a geometrical one but expresses an action which is dynamically real.

Fig. 3 (Plate IX.) shows the process as completed from the records of the trials of Mr. Denny's ship, the *Merkara*. In this, as in the other similar curves, the black crosses show the points deduced from the steam pressures recorded in the individual trials. The curves of indicated horse-power and the curves of slip are also given.

A curious confirmation of the soundness of the method adopted, and of the exactness with which it determines the initial friction, is supplied by the diagram, Fig. 4 (Plate IX.), which represents the thrusts of the *Taupo* and the *Hawea*, which as sister ships ought to have experienced the same resistances throughout. The curves of indicated horse-power for these ships however exhibit a disagreement, and this of a kind which certainly does not at once suggest its true origin; but the corresponding indicated thrust curves, when completed in the manner described, show at once that the disagreement lies in a difference of indicated thrust which is throughout practically constant, and probably expresses in a constant difference between the initial frictions of the two ships' engines. The slight exception to the constancy of the difference which appears at one point of the comparison is manifestly due to an abnormal feature in the *Hawea's* curve, and this is such as to suggest that there has been some small error in the determination of the speed at the point which occasions it, for at this point there is a corresponding irregularity in the slip curve, and one and the same correction would obliterate both irregularities.

Moreover, through Mr. Denny I have received from his friend Mr. Inglis, the reports of the trials of two ships built by the latter—the *Arbutus* and the *Pachumba*, Figs. 5 and 6 (Plate X.); and these also, when similarly analysed, give a precisely analogous result. On comparing these five curves thus analysed and several others in which the analysis was not quite so simple but was I think equally conclusive, it appears that the constant friction is equivalent to from one-eighth to one-sixth of the gross load on the engine when working at its maximum speed and power. And it is not irrational to accept this relation provisionally as the basis of an empirical formula, since the constant friction depends to a large extent on the diameter and weight of the working parts of the engine, and these must be approximately proportionate to the intended maximum strain, subject of course to some allowance for the variation which exists in the types of engine in use. I must admit that the proportion appears to me to be unexpectedly large, but the process by which it is determined is I think so certain

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and definite that I cannot doubt the general soundness of the conclusion deduced by it; and that conclusion seems to me to be one of very high importance and significance—namely, that a screw engine when working at even its most moderate and economical speed, must be understood to be throwing away in the one element of this friction alone, not indeed one-seventh of its maximum power, for the engine may be now working at reduced speed, but a power due to one-seventh of its maximum load. Thus in the case of the *Merkara*, when the ship is steaming at 5 knots in a smooth sea one-half of her whole expenditure of power is due to this circumstance. The question of the apportionment of this large amount of inevitable friction between the several working parts of the engine, and of the proportionate degree in which it attaches to different types of engine as well as of the extent to which the evil is remediable, are enquiries of great importance, but they are more or less out of my reach, and are at all events beyond my present purpose, which is satisfied by the proof—an irresistible proof as it appears to me—that the evil does exist to about the degree named.

But the discovery of the actual amount of power thus expended has been of great assistance to me in the attempt to account for the fact, of which accumulated proof exists, that the total power employed in a screw-ship's propulsion greatly exceeds that required by the nett resistance; and I venture to call the attention of the Meeting to my investigation of this subject as far as I have yet carried it.

The greatness of the excess has become manifest wherever it has been possible to compare a ship's actual resistance at a given speed with the indicated horse-power required to drive her at that speed; and abundant data for the comparison have been supplied in the first place by the dynamometric trials of H.M.S. *Greyhound*, and in the next by the experiments on the resistances of ships of various forms which I am carrying out for the Admiralty by careful dynamometric trials of their models; for among the latter it naturally happens that many forms which have had their nett resistance thus determined, have also been tried on the measured mile, and to these must be added Mr. Denny's ship, the *Merkara*. The result of the comparison shows that as a rule only from 37 to 40 per cent. of the whole power delivered is usefully employed,* and it will be seen that, using the constant friction of the engines as an index of the scale of the friction generally, the 60 per cent. or more of loss can be fairly accounted for.

In the earlier part of this Paper I enumerated the principal elements constituting the gross load of the engines. I repeat the list here. (1) Ship's nett resistance. The power

* In Mr. Denny's ship the usefully employed power is as much as 42 per cent. This however is at the light or trial draught.

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due to this I shall designate effective horse-power, or E.H.P. (2) Augment of nett resistance due to negative pressure created about the ship's stern by the action of the screw. (3) Water friction of screw. (4) Constant friction, or friction of engine as without external load. (5) Friction due to external load. (6) Air-pump and feed-pump resistance. The six elements are force factors, and when multiplied by $\frac{\text{speed of ship in feet per min.}}{33{,}000}$ constitute the ship's horse-power as fundamentally due to her progress, and I shall designate this S.H.P. in making up the account, which will consist of the several elements all ultimately reduced into terms of E.H.P., which is in a sense the origin of them all.* The horse-power due to slip has to be added subsequently.

I proceed to quantify each element in detail, making up the account in the first instance for the highest speed as a point of departure.

(1) This is to represent the ship's true resistance whatever it be.

(2) The augmentation of the ship's resistance by the induced negative pressure under the stern consequent on the thrust of the screw is a circumstance on which I have often laid great stress at the Meetings of this Institution. There is abundant proof of its existence and approximately of its magnitude in the records of the trials of the *Rattler* and *Alecto*, *Niger* and *Basilisk*. Here I will only refer to the more crucial proof of its existence and of its magnitude which has been obtained by our experiments with models. After a model's nett resistance at all speeds has been determined in the usual manner, the resistance is again determined under the conditions imposed by screw thrust. There is brought up behind the model, and quite independent of it, a screw shaft carrying a screw of the required pitch and suitably speeded; the shaft being bracketed out forward from and beneath a horizontal frame which possesses a delicate dynamometrically governed horizontal fore-and-aft mobility, and is suspended below a truck, which at a definite distance astern follows the dynamometric truck, by which the model's resistance is determined. The screw, placed exactly where it would be if it were driving the model, rotates with a speed sufficient to drive it, but without touching it or affecting it except through the hydro-dynamic action which it is sought to measure. The force of rotation employed in driving the screw and the drag or thrust it exerts on the frame which carries it are both automatically recorded, and the speeding is varied until a speed is

* To defer thus the introduction of this form is equivalent to substituting the speed of the ship for the speed of the screw in all the power terms—in the E.H.P. as well as the rest. This arrangement is preferred on the ground that it appears to bring out with special distinctness the circumstance that all the elements enumerated, except slip, are alike virtual additions to the ship's resistance, and would equally exist if there were no slip, while the slip, taken separately and subsequently, represents the additional power expended on all the force elements alike, in consequence of the partial yielding of the point of reaction from which the propulsive force is taken. In virtue of the slip there are so many more revolutions per minute performed by the engine, with its total load—its superfluous load as well as its useful load.

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found at which the total thrust equals the model's total resistance, that is to say its nett resistance + the augment in question. These experiments show that with ships of ordinary form the augment is from 40 to 50 per cent. of the ship's nett resistance, and in making up the account I shall rate horse-power due to (2) as = 0·4 E.H.P.

(3) *Water Friction of Screw.*—The *Greyhound* experiments showed that the additional resistance caused by the screw when it was allowed to rotate freely as the ship went ahead considerably exceeded 0·1 of the ship's natural resistance. Now the speed with which the screw revolved was less than that due to the speed of the ship, and to have driven it at a higher speed would certainly have required more force, or in other words would have been a greater drag on the ship; it cannot therefore be unfair to rate this as 0·1 of the natural resistance. Horse-power due to (3) is therefore = 0·1 E.H.P.

(4) *Constant Friction due to Dead Weight and Tightness of the Moving Parts.*—It has already been shown that this is at all speeds equal to about one-seventh of the total load on the engines when working with the maximum intended speed and pressure. And since the account is in the first instance taken as it applies to the highest speed, I take the horse-power due to (4) as = 0·143 total S.H.P.

(5) *Friction due to Working Load of Engine.*—This at the maximum speed can hardly be taken as being less than the dead-load friction, when it is borne in mind that the forces to which it is due exceed by many times the dead weights of the moving parts, to which principally the dead-load friction is due; I therefore rate it at the same amount, so that S.H.P. due to (5) is = 0·143 total S.H.P.

(6) *Air-Pump Resistance.*—According to Tredgold the load on the engine due to the air pump is between one-tenth and one-twentieth of the whole load on the engine. I shall set it down as 0·075. Thus the S.H.P. due to (6) is = 0·075 S.H.P.

The horse-power due to the several elements, worked out on the foregoing basis and combined, may be tabulated as follows:—

Horse-power due to	No. 1 =	E.H.P.	
Ditto	No. 2 =	·4 E.H.P.	
Ditto	No. 3 =	·1 E.H.P.	
Ditto	No. 4 =		·143 S.H.P.
Ditto	No. 5 =		·143 S.H.P.
Ditto	No. 6 =		·075 S.H.P.
Or in combination—	S.H.P. =	1·5 E.H.P. +	·361 S.H.P.
So that—	·639 S.H.P. =	1·5 E.H.P.	

Or— $\text{S.H.P.} = \frac{1{\cdot}5}{{\cdot}639}\ \text{E.H.P.} = 2{\cdot}347\ \text{E.H.P.}$

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To this must be added—Slip = ·1 S.H.P., making I.H.P. = 1·1 S.H.P.*

Thus— I.H.P. = 2·582 E.H.P.

$$= \frac{100}{38{\cdot}7} \text{E.H.P.}$$

Or— E.H.P = ·387 I.H.P.

And this conclusion agrees very fairly with what, as I have already pointed out, more general experience has led me to adopt as an average expression of the relation between indicated and effective horse-power—namely, that at high speed the former is about 2·7 times the latter, or the latter $37\frac{1}{2}$ per cent. of the former.

To convert the formula from one adapted to high speed only to one adapted to all speeds it is necessary to keep the term involving constant friction separate from the rest, for it represents simply the effect of a constant resistance operating with the existing speed of the engine. In shaping the formula I shall adhere to the co-efficient 2·7, derived from rather broad experience, in preference to the co-efficient 2·582 just now built up on somewhat hypothetical data, assuming however that the constant friction is equal throughout to one-seventh of the maximum load. Of the 2·7 E.H.P. which make up the I.H.P. at the maximum speed V, one-seventh part or ·385 is the part due to constant friction, leaving 2·315 as due to the other sources of expenditure of power. And to express the I.H.P. due to constant friction at any other speed v, we must alter the co-efficient in the direct ratio of the speed. So that the term becomes $\frac{v}{V} \times$ ·385 × E.H.P. at designed maximum speed. Thus the formula for I.H.P. at any speed v is as follows:—

$$\text{I.H.P.} = 2{\cdot}315 \text{ E.H.P.} + {\cdot}385 \frac{v}{V} \times (\text{E.H.P. due to V});$$

Or if we finally sever the useful from the collateral expenditure of power, it stands thus—

$$\text{I.H.P.} = \text{E.H.P.} + 1{\cdot}315 \text{ E.H.P} + {\cdot}385 \frac{v}{V} \times (\text{E.H.P. due to V}).$$

The several elements thus calculated are shown in combination in Fig. 7 (Plate XI.) approximately to fit the case of the *Merkara*, but the figure *mutatis mutandis* will represent pretty nearly their relative value in the case of other ships. The results are given not as expressing a complete solution, but as a well-considered step towards it.

* *See* foot note, p. 173.

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DISCUSSION.

Professor OSBORNE REYNOLDS: Might I ask Mr. Froude to make it quite clear whether he takes into consideration the work spent in giving slip to the water—whether there is not another part of lost work, so to speak, which is nearly represented by the augmentation in the speed of the ship which would result if there were no slip in the water? Whether the speed factor by which you should multiply the indicated thrust to get the indicated horse-power is not the ship *plus* the slip?

Mr. FROUDE: The slip is summed up in the total speed of rotation.

Professor O. REYNOLDS: Really you would multiply this, not by the speed of the ship to get the horse-power, but by the speed of the ship *plus* the slip of the screw.

Mr. FROUDE: The calculation really depends on the ratio of the speed of the screw to that of the piston—taking the steam pressure on the piston. We will suppose that the pitch of the screw is four times the stroke of the engine—that is a simple case—then for every revolution of the engine there would be four piston strokes, which would together be equal to the travel of the screw due to one revolution of the engine. The thrust on the screw should be exactly equal to the pressure on one piston.

Professor O. REYNOLDS: Usually we attribute the loss in the great difference between the power employed and the power spent in driving the ship to what is spent in giving the backward motion to the water, whereas here you make no comparison between the power spent in forcing the ship forward and that spent in giving a sternward motion to the water, but you simply take these two together and calculate what power besides both of these is, as it were, spent by the engines.

Mr. FROUDE: The slip takes account of both the rotation and the endways motion.

Professor O. REYNOLDS: That I understand.

Mr. FROUDE: I put in a term for the slip which includes the whole motion of the water whether circumferential or otherwise. There is a diagram there in which the different elements are all expressed by curves; the ordinates between the curves represent, in connection with the speed, the amount of power going in each one of the elements.

Professor O. REYNOLDS: I understand it now, but I did not read it in the Paper. That was the question which I was wishing to ask. It seems to me that we have here—if I may say so—a simplification of the subject of screw propulsion, such as must lead us to a degree of knowledge altogether beyond what we have been able to arrive at before. This clear statement of what the causes of the loss of work in a steam ship are must lead to our being able to deal with them in detail, and modify the arrangements in such a manner as to check them as far as it is possible. I should like to ask Mr. Froude, if he would venture on such an opinion, to tell us what portion of this loss is one that is capable of being reduced and modified?

Mr. FROUDE: I am sure I do not know that. That is a very wide question, which I would rather leave to the determination of results than offer suggestions for improvement.

Mr. NATHANIEL BARNABY: I should like to say, my Lord, that what Mr. Froude is doing is of the very highest interest to everybody here; to the naval architect, and I hope to marine engineers also.

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It seems to me that they must feel that Mr. Froude is discovering how it is we lose such an enormous proportion of the power which is given out by the engines. It is lost somewhere, and he has been trying to ascertain where it is lost. He is feeling his way to all the elements, and among them he finds that important one to marine engineers, how much is due to the constant friction of his engines; and in that way I think we shall learn who makes the best engines. Of course these experiments cannot be made without a great expenditure of time and money too. The experiments made by Mr. Denny are such as we owe him our best thanks for, and I am sure that anything I can do in endeavouring to impress upon the Lords of the Admiralty the importance of going on with the experiments which Mr. Froude so much needs, in order to enable him to discover the elements of loss he is in search of, I shall do with the greatest pleasure.

Mr. Charles Lamport: I wish to ask Mr. Froude whether he has considered in his calculations the ratio between the consumption of fuel, as the generator of the power, and the effect on the propulsion of the ship, as the ultimate result? Mr. Barnaby says that, with regard to shipbuilders and marine engineers, the cause of the loss of engine-power is very important to be known. I may add to that, that it is more important for the shipowner to know the loss as regards the generative or fuel-power. I have heard it said that four-elevenths of the amount of heat generated is all that is rendered effective in the engine, and I think if I read Mr. Froude's experiments rightly as regards the dynamometric progress of the *Greyhound* that only one-tenth of that four-elevenths is utilised.

Mr. Denny: When I first began my experiments, I did so because my confidence in every one of the speed formulæ had been shaken, and most completely shaken, in the well-known V^3 common to all the formulæ. That quantity I found, even in very partial experiments, was totally wrong, or as nearly as possible totally wrong. Now with reference to what Mr. Froude has said in his Paper, I would first of all remark on what he has stated as to the expense of conducting these trials. He really has credited my firm with a far larger amount of self-sacrifice in these trials than we have any right to, because they can be conducted in any single ship in the length of one day, if it is an ordinary one and not an extreme winter day. I should not like that any gentleman here who might be induced to go into these trials should be deterred from them by Mr. Froude's statement, which he has I believe made in kindness to me, and which I therefore feel all the more bound to correct. I now come to Mr. Froude's remarks on the composition of the indicated thrust, and specially to his analysis and detection of the amount of the initial friction. For the verification of this analysis he particularly wished some trials with a lower extreme speed than 4½ or 5 knots. Unfortunately, I was not able to make all the trials I wished, or to carry out the instructions Mr. Froude gave me, as at the time we had only four steamers on hand; but my friend Mr. Inglis who is sitting beside me did this, and if you turn to his trials of the *Pachumba* you will see that the lowest speed is about 3 knots. Now it is ordinarily assumed from trials which we shipbuilders sometimes make that it is only too easy to get slow speeds, but I can assure you it is extremely difficult to make such a slow-speed trial well. The care and patience required are something very much beyond what is necessary for any number of larger speeds; and I never expected, nor do I think Mr. Froude expected, that such a success would be achieved as to reduce the lowest speed to about 3¼ knots which you see there. I may also mention that Mr. Inglis says he is ready to supply Mr. Froude with the indicator cards taken off the air feed and circulating pumps of the *Mecca*—a steamer which Mr. Froude knows, and which was tried progressively. I do not wish to detain you with

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unnecessary remarks, but I must really enter upon one point which I feel a little unpleasant to myself. I have the pleasure of the friendship of Mr. Froude, and of another very able man, Mr. Mansell, who is known to many of our scientific shipbuilders here. When Mr. Froude discovered by his analysis the way in which it was possible to measure the initial friction, I remember having a conversation with my friend Mr. Mansell, and I put it to him that Mr. Froude had thoroughly explained the discrepancies of the *Hawea* and *Taupo* trials by reducing them to indicated thrust. My friend Mr. Mansell at the time did not seem to think that this had been attained. Shortly afterwards however he came to me, and I believe he had forgotten what I had said to him, but he had come upon the same idea, and he has worked out this idea in a very interesting way. You will perhaps excuse my making use of the black board to show you this, as it is a point which I am very anxious this Institution should clearly understand. Mr. Froude has, and has alone, the priority for the discovery that the amount of initial friction could be found out from progressive trials, and it is perhaps the most interesting discovery which has been made with regard to speeds for a very long time. You will see that a different method of analysis has provided us with, although not an exact confirmation, yet a very close confirmation of what Mr. Froude has said. Mr. Mansell's method of analysing was this. You will suppose that these are two scaled arms at right angles of a diagram, similar in all respects to that of the *Pachumba*. Upon the horizontal arm is set off in ordinary arithmetical notation the speeds 1, 2, 3, 4, 5 knots, or whatever they may be. Upon the vertical arm, not the indicated horse-power, but the mean piston pressures equivalent to the indicated thrust (the idea of which, as I tell you, Mr. Mansell had unconsciously borrowed I believe from my suggestions about Mr. Froude) are set off not in arithmetical but logarithmic notation. In fact, the principle of setting off this arm is the principle of Gunter's scale carried out in only one scale. Now if any gentleman would set off on the speed ordinates the amount of mean cylinder pressure or indicated thrusts according to the logarithmic scale already described, as Mr. Froude has done in arithmetical notation, a very curious thing happens [*illustrating on the black board*]. Strangely enough, Mr. Froude's curve becomes a straight line. With regard to what Mr. Mansell did, and I have the deepest respect for Mr. Mansell, you must acknowledge his great ability in seeing that it was possible by this means to show what Mr. Froude has also shown. By simply producing the straight line, and measuring its zero ordinate, he shows the amount of the initial friction of the engines.

Mr. FROUDE: May I ask does that proceed on the assumption as to the law that governs the resistance? It must involve some such fundamental rule.

Mr. DENNY: I do not think Mr. Mansell originally did more than proceed on the notion I had given him of what you had done, and I believe he forgot all about where the notion came from, which is common enough for all of us to do. I have myself occasionally borrowed from my friends; but, when I have been reminded of it, I have acknowledged it, although I could not say at the time where the idea came from.

Mr. FROUDE: I fully agree with that; but I merely wanted to understand the principle on which that line comes out a straight line.

Mr. DENNY: I do not know the principle, but in every case this line has come out a straight line, with one exception. Allow me to say this, because it will be confirmatory of something Mr. Froude will have to tell you in a second Paper. In some of the ships—I think notably the *Merkara*—where the speed

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was for us high, 13 knots, this last curve did not come out straight but turned up here; showing you, at that point, something—which you will see afterwards, and which Mr. Froude will explain to you fully—had happened. What I may call an augmented increase of resistance had taken place there, which of course must have been due to the form of the ship. I know I am taking up a great deal of time; but you will acknowledge that, as to one part of this, it has been a duty forced upon me, and not a part of my own inclination. The other thing that I have to remark upon is merely an additional fact, which is this:—Mr. Froude has described to you the work done in the *Hawea* and *Taupo*, but he has forgotten to tell you one thing about it, which adds a great deal to the interest, namely, that, by mere chance, on the occasion of the trials those boats were identical in displacement; and I think identical in displacement with the *Greyhound;* and not only identical in displacement, but very nearly identical in trim. If anything, curiously enough, the trim was slightly more by the stern in the *Taupo;* which should have had the advantage as the lines were fine. I need not say how much I have appreciated both Mr. Froude's and Mr. Barnaby's observations.

Mr. R. GRIFFITHS: I made some few experiments with regard to this, which were published in a pamphlet brought forward nearly eleven years ago; and at that time I think Mr. Froude promised that he would investigate them for me. I showed him all these things, as near as I could, and I told him that if there was anything further I should be most happy to give it to him; but from that day to this neither Mr. Froude nor any other engineer has controverted that statement. Now the main reason of our loss by the screw-propeller is the shortness of water to the screw. I was at Devonport when they were fitting the casing on to the *Bruiser*, and the Admiralty kindly allowed me to try some experiments on the launch. By that means I found out a great many things not understood. I do not mean to go into them now, as I have to read a Paper this evening on the very subject, which will explain a great many matters connected with this question; but the main loss on screw propulsion is, first, that as you increase the power of the screw she requires more water; and next that she keeps sucking away the water from the stern of the screw. Those are the two main points of loss. To get over that the only plan that I have yet found out is by casing the screw in a tunnel, drawing the water as far forward under the ship for that purpose as possible, so as not to interfere with the water that supplies the space the ship has left; and the next thing is enlarging the mouth of the tunnel, according to the power, so that the increased water may be always supplied to the screw, because I find when the power of the screw is increased she requires more water; and up to such an extent that when you put 16 horse-power on each square foot of the screw you require double the amount of water to supply it.

Mr. J. I. THORNYCROFT, C.E.: I want to say how very much I admire Mr. Froude's investigation of this subject, and what very great importance I attach to it. One thing strikes me as being a large element of loss, and that is the augmenting effect of the resistance of the screw on the ship. I should like to ask if Mr. Froude has made any experiments to show, by removing the screw from the ship sternwards, at how short a distance this evil may be somewhat remedied.

Rear-Admiral ALGERNON F. R. DE HORSEY: From a naval point of view, I desire to say how much I feel gratified and how thankful we must be to Mr. Froude for separating effective horse-power from indicated horse-power. Indicated horse-power has been the bugbear of the whole thing. I hope that, when he arrives at the end of his investigations, we shall then know which engines go best at a slow speed; because after all the real test of an engine is its going well at its very slowest speed. We are

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very much interested on that point in the Navy. We try to save our coals by going slow, and very often do it at a great loss—the fuel is all expended in turning the engines round.

Mr. FROUDE: With reference to Mr. Denny's remarks, I have no doubt by using only two runs to each speed there is a great deal of economy; and if sufficient care is used in analysing the total speed indicated, by the difference of up stream and down stream, very good results can be got from a short number of runs. Mr. Thornycroft asked me what the effect of removing the screw further from the ship was. I have worked that out with a very considerable amount of care, but the investigation is somewhat incomplete. There were great difficulties in the investigation of the more minute parts of the result; and for that reason, instead of saying 50 per cent. is the loss due to the back action of the screw, I put it down only at 40 per cent., to be on the safe side. But our apparatus possesses the power of placing the screw at any distance from the stern; and it is a most remarkable thing to find at how great a distance it produces a sensible increase of resistance. In some experiments which I tried a good many years ago with a small model driven by clockwork, I found that when the screw was removed to about one-third of the ship's breadth from the stern the maximum effect of advantage was produced, but even then there was some little augmentation of resistance; but the sensitiveness of the water beneath the ship, to any adventitious bodies forcing their way is very remarkable indeed. The intrusion of any solid, even the mere experimental screw-shaft, into the water behind the ship produces a distinctly sensible diminution in the ship's resistance. And the body thus forced in behind the ship, while it thus diminishes the ship's resistance, must experience some augmentation of its own resistance; and one of the main difficulties in this trial is to eliminate the collateral effects of the parts of the apparatus that is used in running the screw. No doubt we shall get over that difficulty. I think if the screw were placed something like a quarter of the ship's beam astern of the ship it would be a great advantage, and probably would reduce the loss to 8 or 10 per cent. I quite agree with what Admiral De Horsey mentioned just now, that these results deduced from slow-speed trials are very important. No doubt for a large part of her time a ship of war must cruise at a moderate speed as a matter of economy, and any means of lessening this constant friction of the engines seems to me to be a most important object.

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ON THE COMPARATIVE RESISTANCES OF LONG SHIPS OF SEVERAL TYPES.*

By W. Froude, Esq., M.A., F.R.S., Vice-President.

[Read at the Seventeenth Session of the Institution of Naval Architects, 7th April, 1876; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

The trial of the model of Mr. Denny's ship *Merkara*, referred to in the Paper I have already read, furnished materials for extending and giving practical completeness to a comparison which our series of experiments had already led us to institute between several types of form.

The comparison is interesting, as showing the relation between length and resistance with two types of form—(1) That form in which a straight parallel-sided middle body is interpolated between two ends of greater or less fineness; (2) That in which the whole length of the ship is utilised in fineness of form; the results being worked out for the *Merkara* and three other ships of the same displacement, but of different form and proportions. The lines of these three other forms selected are those which in our series of experiments have been found to give, on the whole, the best results within ordinary available limits of speed. The displacement in each case is 3,980 tons, which was that of the *Merkara* on her trial. For shortness I shall call the four models A, B, C, and D; A being the *Merkara*. A and D represent No. 1 type, but with different proportions and different degrees of fineness; B and C represent type No 2. They have different proportions but the same degree of fineness. The ends of D beyond the parallel middle body have the same fineness as the ends of B and C; indeed all these forms have what may be called the same entrance and the same run, for though their dimensions as well as their proportions of length to beam differ, the cross-sections on which their lines are based are throughout the same, the longitudinal spacing being in each case made proportional to the total length they occupy, or as it may be termed having different degrees of expansion. The Table on next page gives the leading particulars of the four ships.

* Received 4th April, 1876.

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The length as given does not include the screw aperture, taken to be 9 feet. In A the entrance and run are each 3·87 beams; the total length is 9·67 beams; the draught is ·436 of the beam. In D the entrance and run are each 2·08 beams; the total length is 6·25 beams; the draught is ·392 of the beam. In B and C the total length is 7·82 beams and 6·26 beams respectively; in both the draught is ·392 of the beam.

Displacement.		Length.				Extreme Breadth.	Mean Draught.	Area of Skin.	Square Root of Entrance plus run.
		Entrance.	Parallel Middle Body.	Run.	Total.				
		ft.	ft.	ft.	ft.	ft.	sq. ft.		
3,980	A	144	72	144	360	37·2	16·25	18,660	17·03
	B	179·5	...	179·5	359	45·88	18·00	19,130	18·95
	C	154·5	...	154·5	309	49·4	19·32	17,810	17·58
	D	95	95	95	285	45·56	17·89	16,950	13·78

These explanations are a sufficient introduction to the consideration of the several Figs. 1, 2, 3, and 4 (Plate XII.), which give the lines of the several ships; and Fig. 5 (Plate XIII.), which gives their respective curves of resistance, that is to say, curves in which the abscissæ represent speed in knots; and the ordinates resistance in pounds. In studying Fig. 5, perhaps the circumstance which first deserves notice is, that at the maximum speed included in the steam trials of the *Merkara* there is so extremely small a difference between the resistance of these four ships, differing so considerably as they do in form and proportions. Making the comparison at 12 knots, the greatest of the resistances, that of D, is 21,000 pounds; the smallest, that of C, is 18,700 pounds; the difference being only 2,400 pounds, or scarcely over 10 per cent. An interesting light under which to view this amount of difference is that thrown on it by the fact that it is only half of the thrust equivalent to the constant or initial friction of the *Merkara's* engines, a circumstance which indicates how easily a difference in the performance of the ship may be masked by a difference in the performance of the engines. If in comparing the ships at this speed we omit D, as possessing considerably less sharp lines of entrance and run than either of the other three, the differences between the resistances are still smaller, the 20,000 pounds of the *Merkara* exceeding the 18,700 of C by only 1,400 pounds, or 7·5 per cent.; and even at 13 knots, which just exceeds the highest speed included in the *Merkara* steam trials, though the resistance of D has become rather more in excess, yet that of the *Merkara* and B are identical, and that of C, the smallest of the three, is still only 1,400 pounds below theirs. At 13½ knots the resistance of D is beginning to diverge rapidly into excess, and the *Merkara's* is also beginning to diverge in the same

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direction, though less rapidly. At still higher speeds the forms C and B, which have no parallel middle body, show a growing superiority to the *Merkara*, though the longest of them is only as long as that ship, and is nearly 8 feet broader while C, the shorter of the two, is 51 feet shorter; and at the same time 12 feet broader than the *Merkara*. Up to 16 knots the resistance of C is less than that of D, though C is 4 feet the broader and 24 feet the shorter.

The results of the comparison are interesting in their relation to a proposition which I have elsewhere insisted on—namely, that at very low speeds (speeds low as compared with the length of the ship) a ship's resistance, if her form be fairly fine, consists practically of nothing beyond surface friction; and it is worth while to notice how far the proposition is verified in the case before us. The model of the *Merkara* was tied down to a speed lower than we used formerly to include; so that at the lowest speed which her curve of resistance includes I have not data for the verification of the proposition with the other forms; but it is the fact that in the *Merkara's* case at from 5 knots to 8 knots the surface friction is about 92 per cent. of the ship's entire resistance. And referring to Fig. 5 (Plate XIII.), we see that although at 9 knots D, with a less skin, has a greater resistance than the *Merkara*, yet the line of her resistance-curve is converging on the *Merkara's*, and might be expected to cross it at a still lower speed; B, however, which has a skin area rather larger than the *Merkara's*, has, nevertheless, rather the smaller resistance of the two; but C, which has the smallest skin area of all, has also the smallest resistance.

A more practical aspect of the comparison may be made in relation to higher speed; and even in reference to a speed as high as 12 knots it will be seen how valuable a diminished area of skin may be when the effect of fouling is taken into consideration—a circumstance of especial importance to a ship of war which may be under the necessity of keeping the sea for long consecutive periods. I am not able to say how much fouling exactly is to be anticipated thus under any given circumstances, nor again can I say exactly how much extra resistance a given amount of fouling will produce. But our experiments on surface friction show that the substitution of a surface of ordinary unbleached calico for one of clean paint produces just a double frictional resistance, and a foul bottom must often be no less obstructive. For simplicity of calculation I shall suppose a degree of fouling by which the resistance is exactly doubled, and it will be seen that the effect of this is to improve greatly the relative positions of the shorter ships. The construction of the Table sufficiently explains itself.

It will be seen that under these circumstances D, which in the comparison as it stands with the clean skin is the worst of the four, having a resistance exceeding that

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of the mean of the two long ships in the ratio of nearly 1·1 to 1, has become as good as the best of the two, now that the skin resistance is doubled, and under the same circumstances the superiority of C has been notably increased.

Names of Ship.	Area of Skin.	Total Resistance.	Resistance due to Skin Friction alone.	Residuary Resistance independent of Skin.	Doubled Skin Friction.	Total Resistance with Skin Friction doubled.	
A *Merkara*	18,660	20,000	15,600	4,400	31,200	35,600	Assumed speed 12 knots.
B	19,130	19,220	16,160	3,060	32,320	35,380	
C	17,810	18,700	14,890	3,810	29,780	33,590	
D	16,950	21,100	14,250	6,850	28,500	35,350	

The superiority of the shorter ships in respect of handiness need hardly be referred to. Moreover, I cannot but believe that the weight of hull constructionally necessary to the strength of the ship must be considerably less for the shorter than for the longer ship. Mr. Denny indeed is not, I believe, prepared to admit this; but the question raised is one which I think must be capable of something like a general and almost demonstrative solution, and it is one which ought to be treated on general mechanical principles, and not decided by mere reference to the existing Rules of Lloyd's. These however are I trust undergoing revision in very capable hands.

Nevertheless, it must be admitted that in view of the importance of large carrying power combined with limited draught—a limitation which the Suez Canal has done much to emphasize—and I may add, in view of the practical sufficiency of what may be called "moderate speed," the prevailing tendency to great length, including a long parallel middle body, is a fair result of "natural selection;" and this form if rationally treated, is perhaps, under the conditions indicated, the best adapted for commercial success; though where deep draught is unobjectionable a shortened form with no parallel middle would be, as I have shown, unquestionably superior; or were it an object to obtain very high speed, without notable increase of resistance, parallelism of middle body would even with the longer form be inadmissible.

The logic of the circumstances shapes itself thus:—Large displacement means large dimensions, somehow or somewhere; but the limitation of draught forbids enlargement of dimension except in the direction of length, since increased ratio of breadth to depth would involve an objectionably raised metacentre and objectionable increase of skin; greatly extended length has therefore, for mercantile purposes, become essential to large carrying power. Now, with a very long ship, if the ends are so far fined as in

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effect to limit the resistance to surface friction, the parallelism of the remainder clearly assigns a valuably increased carrying power to the ship as a whole; or, what comes to the same thing, secures a given carrying power with less total skin and therefore less resistance at moderate speed. What I contend against is, not the parallel middle body *per se*, but the mistaken idea which to most minds forms the basis of its justification—the idea, namely, that to lengthen a ship by merely introducing a parallel middle involves no material increase of resistance, the supposition being that the middle thus added will follow unobstructed through the opening made in the water by the full-sized ends.

In conclusion, I must remark that the performance of Mr. Denny's ship is somewhat better than previous experiments had led me to expect it would be; for I had not expected to find that, after taking account of the resistance due to surface friction, her residuary resistance would be barely less at 12 or 13 knots than that of B, a ship of the same length and certainly of finer lines. Whether this rather unexpected goodness lies in some speciality in the lines of the entrance and run, or in the form of the midship section, or whether it merely indicates that at a speed so moderate compared with the length of the ship's entrance and run as 12 knots it matters little what the lines are, provided they do not fall short of a certain standard of fineness,—is an important question which I shall not feel has been decisively answered till a series of experiments bearing on the point shall have been completed. Some additional steps in the series have been suggested by the present examination.

DISCUSSION.

Mr. WILLIAM DENNY: I hope you will excuse my making a remark or two. As the *Merkara* is a ship built by my firm, I may be able to say something that will elucidate the reason for her being made in a rather peculiar form. I think Mr. Froude has very well put the war requisites. The war requisites are, primarily, a short length of side requiring armour, and a small amount of skin to be fouled. But our requisites in mercantile naval architecture are different; and I would especially call attention to one of them which is being more and more felt every day. Yesterday I referred to the unfitness of great merchant steamers—especially of high speed and as built now—for carrying heavy armaments, because they possessed so slight a margin of stability; and I wish that this fact should be kept very carefully in mind. Now some advantages of the *Merkara's* lines—if I may presume to point them out to you—are that, so far as Mr. Froude has shown you, they have fulfilled all the requirements of speed; but they have greater advantages than these so far as stability is concerned. In the *Merkara* we tried to get

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a great depth, for the purpose of getting our passengers berthed well out of the water; and as we had a large number of deck houses, it became an important thing to discover how we were to get a large amount of stability. You will see that the question was a difficult one, when you consider that the form of the midship-section of the ship is not a form conducive to stability, but one which tends to lower the metacentre very considerably, on account of the great ratio of the lower form to the upper breadth. I came to the conclusion that by driving the whole mass of the ship into the centre—by making a straight body and sharp ends—that, for the area of the load water-line, I should get the largest result in stability. This I was sure would answer satisfactorily, and I am certain that the cubes of the ordinates of the load water-line of the *Merkara*, massed together, are larger than the cubes of the ordinates of any other water-lines of the same area and proportions, worked out in a different way, the result of which would necessarily be to club the bow and stern. We did not attempt in this design to do what Mr. Froude says so many have attempted, to save resistance by a straight midship body, with the very faulty belief that a straight body amidships has no resistance, because that is a mistake; and I was sorry to hear Mr. Scott Russell speaking yesterday about adding 25 feet and 25 feet, without considering the augmented resistance from the skin surface, and also without considering the augmented weight, which would have reduced his coal, from the extra strength which Mr. Froude has spoken about, and which I am sorry to say at one time I contested. However, one can always acknowledge errors, and I acknowledge mine now. That is all I have to say. I merely wish to point out why the *Merkara* was designed on this principle. She came up to my expectations. She is a very stiff ship for her depth, and I do not think any other way than having a full water-line aft, which is apt to destroy the speed, would have been productive of such good results.

Mr. J. Scott Russell, F.R.S.: I wish to correct a mistake. I hope I did not say that the lengthening of the middle body could be accomplished without any increase of resistance. Did I say so?

Mr. Denny: You did not say that; but you led it to be inferred, because you added 25 feet and 25 feet to produce the amount of coal-carrying space. Your first 25 feet carried a certain amount of coal, your second 25 feet carried a certain amount of coal, and so on, but there was no allowance for the increased weight which would be required in the construction, nor, so far as I can see, the increased skin resistance.

Mr. J. Scott Russell: Then I am very sorry that I was misunderstood, because the 25 per cent. contained a very large allowance for the additions which have been alluded to; and if Mr. Denny takes the trouble to find out, he will discover that all those additions were amply allowed for; and if I had no such additions I should not have added so much as the 25 per cent. Allow me therefore to correct what I said yesterday, only in this one respect, to prevent any error similar to that into which Mr. Denny has fallen. I correct it therefore by stating to you, that if you do not make these allowances you will find 20 feet added will do what I stated; but in order to be on the right side I gave you 25 feet. Allow me to sum up in one word what I meant to convey upon that subject; and I am sorry that, to a gentleman so intelligent as Mr. Denny, I utterly failed to make myself understood. That shows it was my fault; but to prevent the possibility of a misunderstanding, allow me to say simply this:—When you have fixed the dimensions and forms of a vessel for the purposes necessary to go at your speed through the water, you then have to prepare your ship for the length of voyage she has to make and the fuel she has to carry, in addition to what you have already obtained for the ship. When you have got to that point

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in your calculations, what I say and repeat in the most distinct manner is this, that the additional length must be given to the central body of the ship in exact proportion to the length of voyage that the ship must go without coaling; and although it will require a separate minute calculation for each ship, I say that 20 feet and with a margin 25 feet of length must be added for each 1,000 miles of voyage which that ship has to perform. Permit me, therefore, to give a further explanation on that one point, in conformity with the request of a distinguished gentleman in the Admiralty who desires me particularly to call attention to the fact that the length given to the *Warrior* class of ship was the length given, by necessity, for the length of voyage for which that ship was built to carry fuel. Permit me to say, in justice to the original designers of that ship—who I am afraid have nearly all gone to the other world except myself—and to your Lordship, an original promoter of that ship, that the original length of that ship would have given her all her speed, would have carried all her armour, and done all they wanted in the way of performing very short voyages. The additional feet added were precisely the number of additional feet added for the service for which the Admiralty, who superintended the design of that ship, intended her; and when I say to you, my Lord, that that ship was intended to steam more than 6,000 miles in any weather without coaling at high speed, I think, my Lord, I have shown any professional man here that that additional length was absolutely indispensable, along with the other qualities of the ship. There is one thing more which I think, also in justice to the original man responsible for the design of that ship, should be generally known. Admiral Eden was one of the men who gave the most professional thought, after Sir Baldwin Walker, to the construction of that ship; and Admiral Eden was the man who prescribed that she should at least have 4½ inches of armour. He was the man who also stated that, confining the armour to the central citadel, he was willing that the ends should be left without armour.

The PRESIDENT: Admiral Eden was not in the Admiralty at that time.

Mr. J. SCOTT RUSSELL: Not when she was built, but when she was first proposed. I am talking now of the original proposition, which was made a year or two before. The construction was about two years after that. He then settled also another most important point, my Lord, which has been lost sight of—that in addition to the armour-protected battery in the inside of the armour, an equally powerful armour should cover the whole area of the vessel at both extremities. There was also an original element which has been perhaps since lost sight of, and I think you will see there was an amount of foresight in that which the designer ought to have full credit for. It was a forethought, because it was an understood arrangement in the construction of the *Warrior* class, that so soon as the weight of the armour and the power of the guns should have so increased that that armour was no longer able to protect the ship against the guns of the day, arrangements were made in the original design which rendered it perfectly easy to increase the armour at a very small cost and with no loss of time up to the point required.

Mr. FROUDE: I think I have very little to say upon the point. There is one thing in reference to the value of long ships, which I omitted to mention in the Paper, and therefore I mention it verbally, and that is their unquestionable advantages in a sea-way. A very long ship will seldom meet a sea that will make her pitch. It is undoubtedly easier for a ship, if she has height enough, to go straight through the waves than to be set dancing upon them, first plunging her head downward into each wave, and then lifting her head high above it. I believe very often these long ships, in moderate weather, get along very much more smoothly, and with less strain on their engines, because they escape the bobbing up and

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down they would experience if shorter. That is an advantage on the side of very long ships which we ought to give them credit for, but which I think ought not to make us forget the fact that increased breadth with diminished length will very often produce a diminution of resistance.

Mr. J. Scott Russell: I am not an advocate for having a foot added to the length of any ship which it is possible to dispense with.

The President: I am sure every one will agree with me in saying that we are very much indebted to Mr. Froude for his two very able Papers which have undoubtedly contributed very much to the value of this Session of the Institution. I have to add it is with great regret that I must intimate to you the clock opposite warns me. I am so situated that I must request you to be kind enough to release me from my duties at this moment, as I have a good deal of other business to attend to, but as Sir Frederick Nicolson has kindly consented to take the Chair this evening, perhaps he will do so now. I hope it will be understood that I have not the least desire to offer any impediment to the Discussion on the next Paper, "On Raising Sunken Ships," which Paper I am very sorry I am not able to stay and hear, as I think it is upon a most interesting subject.

[Sir Frederick W. E. Nicolson, Bart., C.B., Vice-Admiral, then took the Chair.]

The Chairman: As Lord Hampton has called upon me to take the Chair, I do so in obedience to his desire, but I do not think the noble Lord's logic is very good. He says because I have consented to take the Chair in the evening that therefore I am bound to take it now, after a very long sitting; however, I will do what I can.

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ON RECOVERING SUNKEN AND STRANDED VESSELS.*

By Henry F. Knapp, Esq., C.E.

[Read at the Seventeenth Session of the Institution of Naval Architects, 7th April, 1876; Vice-Admiral Sir F. W. E. Nicolson, Bart., C.B., Vice-President, in the Chair.]

The immense amount of wealth continually being lost in all parts of the world by sunken and stranded vessels being abandoned, because of the considered impracticability or impossibility of attempting to save them by any previous known method, or if attempted afterwards abandoned, because of their destruction by the action of the sea before salvage is effected, mainly because of the improper appliances and consequent slow manner of working a wreck, renders any improvement in means for saving maritime property a question of national as well as local or individual interest.

Though some wonderful and great improvements have been and are continually being made in all branches of arts and manufactures, the art of recovering sunken and stranded vessels seems to have remained to this day the same that it was centuries ago, excepting incidental improvements to pumps, diving apparatus, &c., which, though valuable in themselves, have not been of sufficient importance to produce any radical change in the old style of doing such work, but are merely adjuncts to the style; and the art as worked to-day is the same "heave-and-haul" arrangement, as regards taking off stranded vessels, that it has always been, while the idea of attempting to raise a vessel of any size and weight, sunk in 40 to 100 feet of water on the open coast, has always been regarded by practical people as too absurd to be thought of. That the backward state of this art should always continue would be unreasonable to suppose, and the fact that it has continued so long is probably largely due to the contempt naval people have to any theory not fully and successfully demonstrated, thus nipping in its infancy all attempts at progress.

As regards the recovery of the *Vanguard*, theoretical ship-raisers have had complete and unlimited possession of the field; as all practical ship-raisers—*viz.*, old hands

* Received 7th March, 1876.

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at such work—have stood in the background and condemned as impracticable any attempt at her recovery.

As the public in general have but a faint idea of what is practicable, and practical ship-raisers have not a thorough idea of what is impracticable in raising sunken vessels, it may not be out of place to refer superficially to some of the many plans proposed, as well as plans practised for accomplishing such work.

As regards pumping out a deeply-submerged vessel for effecting her flotation, it is impracticable for the following reasons:—

1.—On account of the immense and costly difficulty of making her decks, hatches, &c., water-tight.

2.—If the vessel could be made water-tight, water will not lift on suction more than 25 to 28 feet high, and a force pump could not well be arranged to work under water.

3.—Allowing these two insurmountable difficulties to be overcome, the pressure of water being $\frac{4}{9}$ths of a pound to each vertical foot, would give a pressure in an ordinary case of fire of 10 to 50 pounds per square inch on her decks and hull, which would quickly collapse the entire fabric.

4.—Removing all these difficulties, the vessel, having no controlling buoyancy to keep her upright, would turn over in any shape in her upward movement, which would generally be the cause of her going immediately to the bottom again, provided the operation took place in deep water.

Another plan proposed is forcing air below decks, and thus displacing the water. The first and fourth named difficulties of the previous plan pertain to this plan also; besides which, if sufficient displacement were created to lift the vessel, the decks would have to sustain the entire dead weight of the ship, and as no decks were ever put in sufficiently strong for that purpose, this plan may be considered impracticable.

As some people have claimed that ships have been lifted in this manner, it is well to cite a case:—Take a ship submerged to the very ordinary depth of 50 feet, air is forced into her, and one end is seen to come up before the other, provided the previous-named troubles are overcome: then one end is afloat and the other end is submerged 50 feet; it requires more air to displace the water from the submerged end before it will come up. Under these circumstances the pressure of the entire body of air within the vessel is co-equal with the pressure due to the depth of water at the point of impingement of the air and water—say at the depth of 40 feet—in which case the pressure inside the vessel would equal 18 pounds per square inch, counterbalanced at the upper end by

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nothing, but gradually towards the submerged end by the external increasing pressure of water in accordance with the depth. It certainly does not seem plausible that a ship or her decks can sustain a bursting pressure of 18 pounds per square inch—a pressure that has been sufficient to explode a steam boiler before now: in the case of a vessel lying as deep as the *Vanguard* this pressure would be fully 50 pounds per square inch.

In general, when lifting power has been required for raising sunken vessels, surface buoyancy, such as old hulks, barges, &c., has been for ages the universal method for getting a lift on each tide—a slow, costly, and risky mode of operating when the wreck lies deep and the tides are low; but even at this its use is strictly confined to the still waters of rivers and harbours, as long experience has proved that surface buoyancy is decidedly impracticable for outside work, as it is impossible for it to stand the rough undulating seas which invariably carry it away before the wreck is raised, snapping all its connections and greatly endangering the lives of the operators.

After many costly trials, such buoyancy, in fact, has become quite obsolete for working in a sea-way by reason of its own difficulties, and not by reason of any superior means having displaced it.

In lieu of any practical buoyancy having been introduced up to this time for outside work, wrecks lying in exposed positions are universally abandoned, leaving a loss of millions yearly to British underwriters and the people generally, much of which will eventually be saved when the importance and necessity of increased salvage once becomes fixed in the minds of those interested.

A primary and important condition pertaining to outside work is that when a lift is once taken on a sunken vessel that it be accomplished completely and quickly, and the vessel towed immediately into smooth water, as from the beginning to the ending of the operation there is constant danger to the undertaking by reason of sudden storms coming up, and the accompanying heavy running seas, currents, &c., to which surface buoyancy is constantly exposed and unable to withstand. Besides total abandonment it is sometimes necessary to incur an additional expense in blowing up a vessel sunk in a channel-way. Such blowing-up operations are continually taking place in various parts of the world, the value of the vessel being entirely secondary to the necessity of clearing the channel; and the fact that engineering science has hitherto failed to cope successfully in raising sunken vessels in an open sea-way, though in inland waters and bays protected from the undulations of the sea and heavy weather there is very little work abandoned if it has any value.

By the loss of the *Vanguard*, and the consequent discussion by the public of the various plans of raising her, one most important element has been brought to the

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surface, which, if those interested will allow themselves to rightly consider, will result in compensating the nation yearly for the loss of many *Vanguards;* in fact her loss may prove the cheapest and most valuable lesson that could have been received in national economy for many years. The important point of these discussions is the appropriateness of compressed air, otherwise the pneumatic system of recovering sunken and stranded vessels. That this system, when properly applied, will eventually be the means of saving millions to the nation needs but little thought to fully comprehend on the part of those acquainted with the great advantages of air over any other power in the great engineering feats of the day. It is doubtful if Mont Cenis or Gothard would ever have been pierced by a tunnel, or that the engineers of the day would ever dream of boring a tunnel under the Channel, but for the fact that, by the use of air, things that were quite impossible in previous ages are rendered simple and easy of execution, solely by reason of the facility with which compressed air can be used.

Though the success of the above schemes may be said to have depended entirely on compressed air as the means of their accomplishment, there is an industry which it is reasonable to say is far more appropriate and dependent on this power than any of the engineering feats named, and that industry is the recovery of sunken and stranded vessels; because by its use all snapping jerks to the chains are entirely avoided, and moreover the instant the vessel leaves the bottom she comes to the surface, and may be immediately towed into a harbour or beached.

Among the few methods of using compressed air for ship-raising, a composition of rubber and canvas bags early took the popular fancy, and some thirty-five years ago a few small vessels were raised by them on the inland rivers and lakes of the United States; but in a short time the system seems to have died out, for not till 1844 or 1845 was another attempt made, when the inventor or manager of them obtained a contract from the United States Government to raise a sloop of war sunk in a channel-way somewhere in the Mediterranean, and which the American Government had been requested by the English Government to remove. Though the bags had been built with the greatest care, regardless of expense, they were never able to stand the strain of the air pressure, as they readily burst before getting filled; for which reason they were abandoned, and the vessel was eventually blown up with gunpowder.

The system was again taken up in New York in 1852 or 1853, by the formation of a company with a large amount of money (about $75,000 paid in), and a fine large steamer, called the *Saxon*, was fitted up with the most improved air-compressor apparatus and a large number of air bags of from 15 to 25 tons capacity, each built on an improved system for strength, and also in respect to escape valves for relieving the

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pressure in them as they came to the surface, as for each 33 feet they rise the air pressure within them must be diminished by one atmosphere by escaping, in order to avoid the danger of their being burst by over or uncompensated pressure; to avoid which the Russian Government (who have lately adopted this system), even with their improved valves, have to adopt the utmost caution while working them, being, it is said, under the necessity of taking a lift of only 10 or 12 feet at a time, and thus prolonging an ordinary operation several days—a circumstance that would generally prove fatal to success in the rough waters bordering on the Atlantic or in the Channels.

Notwithstanding the strength of the bags of the New York Company, the excellence of their valves, and the experience of the operators, many of them often burst on coming to the surface and cause the vessel to go immediately to the bottom again, though a few craft have been successfully raised by them: however, be the cause what it may, the plan failed, and I believe that air bags have never been used in the United States for ship-raising from that day to this.

That rubber bags are likely to be more successful in Russia than they were in the United States is very doubtful, as also that they will ever come into general use, judging from their inordinate first cost (which is said to be some £250 for a 60-ton bag), together with the enormous amount of nursing they require in operating, which is positively impracticable in a sea-way, and their liability to be punctured by coming in contact with some sharp protuberance of the vessel, and also by the certainty of their being worn and chafed by the constant motion given them by the currents and tides. As the bursting strain on these bags increases with the square of their size, it is a prime necessity that they be made of small capacity, which is another objectionable feature. The tensile strain on a bag 12 feet in diameter by 20 feet high, equal to 60 tons capacity, when submerged and inflated will amount to about 1,200 pounds to each vertical transverse inch of the material of which it is built, along its circumferential zone, at that part having the least compensating outside pressure. Such a strain seems inconsistent with durability and the nature of the work; besides which all compositions of rubber are subject to rapid decay from a sort of dry rot.

Having been connected with salvage operations for many years in the United States, I have been enabled to observe and study the many difficulties attending the raising of sunken vessels, as also the difficulties of taking off those that are stranded, and from experience gained in the trade have been enabled to devise and complete an apparatus and system that avoid the existing difficulties pertaining to other methods without creating any fresh ones.

The first which I sought to overcome was in passing chain cables under a sunken

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vessel. This part of the art has generally been done by a process called "dragging," *viz.*, getting the bight of a chain under a vessel's end and sawing away on it till it is worked to the position wanted; but this process is impracticable when the vessel is a large one and settled to any extent in the sand, though on small vessels it is not very difficult.

My method of chaining is to utilize a small size (one to two inch) piece of curved gas pipe or tube, connected to a force pump by means of a flexible hose, the water or air from which washes away or softens the sand or mud and gives easy entrance to the tube under the wreck, through which is afterwards washed a float with a small line attached, the float rising on the opposite side of the wreck with the line, which is made the vehicle for drawing under a larger line, and so on till the chain cable is drawn under.

It is proper to say that it is only necessary to penetrate the mouth of the tube a little past the keel of the wreck, as after the water or air passes out of it either will take the direction offering the least resistance, which is invariably upwards, and thus the upward passage is made independent of the tube. This process has been done with facility on the hardest sandy bottoms, which are even more difficult than clay. In case of obstructions a small torpedo passed through the tube offers ready means for effecting a clear passage and breaking up stiff clay, &c.

The next important novelty of which this Paper treats is the lifting buoyancy. In devising this buoyancy, my first aim was to get an apparatus that would always be under control, and safe from the effect and contingencies of storms, currents, &c.—that is, when the buoyancy was in position alongside of the wreck it would stay there, unaffected and immovable, till the proper time came for raising the vessel. More than this could not be expected or even desired, and this advantage alone will produce an entire change in the system of ship-raising as hitherto practised. Let it be understood that, as each part of the operation of raising a wreck is completed, it will remain completed independent of the weather, delays, &c., until all is ready for bringing the ship to the surface; that it will be as practically easy to raise a ship like the *Vanguard*, lying in an exposed and open position, as it is to dock the *Iron Duke*. Under such conditions it becomes merely a question of ordinary labour, with no impracticable difficulties to overcome, and no risks to take of having the work spoiled by the elements.

A buoyancy to meet these conditions must necessarily be submerged, and the only practical power for working a submerged apparatus is compressed air, the positive expansion of which, as it comes to the surface, must be provided for, otherwise it will burst from excess of internal pressure, even if built of the heaviest boiler plate. For affording this relief of pressure, various sorts of complex valves have been

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resorted to in connection with air bags, but never with satisfaction except in bags of impracticably small capacity; for, though a ship may be raised by pig bladders, the cost of attaching and inflating a sufficient number would unquestionably prevent their utilization; and conversely it is manifest that the buoyancy should be as large as possible consistent with facility of manipulation.

The principle of this lifting buoyancy is a "pontoon" or "jack," having an open bottom, but otherwise air-tight. These are built of light boiler plate, of from 50 to 600 tons lifting power each, the larger size being divided into several (three or four) transverse compartments. They are floated in proximity or alongside the wreck, and by letting the air escape will sink to the bottom. Each pontoon is connected to a pump by a flexible hose while being arranged alongside a vessel, so that the instant the pontoon reaches the bottom suction may be effected on it, so that it is quickly forced into the bed below—flush with its top if necessary—by reason of the superincumbent weight of water and atmospheric pressure on its top. This ability of being sucked into the sand is the only possible manner of at all times securing a buoyancy against the contingencies of storms, tides, &c.; and as each pontoon is placed in position, it will remain immovable while the remainder of the pontoons necessary to lift the vessel are arranged for a month or a year; and when they are all properly attached, and compressed air is forced into them, driving the water out through their bottoms, the necessary amount of displacement is effected and the vessel brought to the surface; the surplus air resulting from expansion as they rise having free escape from under the edges of the open bottoms. With the protection thus afforded, by sucking the pontoon into the mud or sand, the weight and size of the sunken vessel to be raised becomes of secondary importance, as it is only a question of more or less buoyancy being applied, which in turn is only a question of labour, as the risks of derangement and loss are *nil*. It is preferable to connect the pontoons together by flexible hose, after being arranged about a vessel, so that when one is operated on the air will find its level in all that are so connected.

In raising a deeply-submerged vessel it is necessary to place about 10 per cent. of the buoyancy required to float over her decks, so as to give her a low centre of gravity, as this distribution insures her coming up squarely on a level. The proper distribution of these pontoons round a vessel may be practically done by good judgment alone, but can be positively ascertained by trial starts on portions of the buoyancy before making the grand effort. Before sinking the pontoons the vessel should first be chained with the proper number of cables, each of a sufficient length to pass under the keel and reach from rail to rail; from the ends of these cables there will be leading lines to reach to the surface of the water, which lines will be passed through adjustable channel-ways in

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the pontoons, and as the pontoons sink these lines will draw the ends of the cables up through the channel-ways, where they will be clamped on top of them. Also, in sinking the pontoons, these lines will be the means of placing them directly alongside the vessel in the desired position: the cables may be evenly tightened by preliminarily raising the pontoons with a small quantity of air, and then allowing it to escape, &c., by which means the cables will be made to have an equal strain. The channel-ways in the pontoons are simply flexible hose that can be arranged to take a chain from any desired angle, as various wrecks may sometimes require; the pontoons may be moved from place to place with facility over any sea or distance on a draught of water not over 2 feet, as they are carried on a couple of longitudinal cylinders, one on each side, and so arranged that in sinking the pontoons will drop from between them, always in upright position, and at any speed the operator may desire. These cylinders also facilitate getting the pontoons in position about a wreck, when they may be detached and moved away. As any part of the full weight of a pontoon may be reduced by reserving in it a certain amount of air, one operator can readily manipulate the sinking of one of 400 to 600 tons capacity. A pontoon capable of lifting, say 300 tons, will only weigh complete 15 tons. The approximate cost will range from 19*s.* to 27*s.* per ton displacement, according to the size, the larger being the least costly.

Considering that their durability is equal to years of service, their cost is a mere bagatelle, especially as they are applicable to nearly every vessel stranded or sunken (within reach) on any coast.

Though the manner of working them on stranded vessels is somewhat similar to sunken vessels, there are some special points of advantage they possess on stranded work, beyond the mere act of lifting, that must not be overlooked.

When a vessel becomes stranded on a sandy beach the peculiar action of the sea either banks her up with sand or cuts the sand out from under her, the first of which makes it exceedingly difficult and frequently impossible to move her off by the ordinary well-known means of warping alone; and it is a common resort to attempt to dig a channel to move her through into deep water; but this is but rarely successful, because the run of the sea will fill up the channel almost as soon as formed; though in very sheltered spots it is partially successful, but an extremely expensive and slow method. Such digging is done by steam dredger or manual labour. The action of the sea in cutting under a vessel is the great cause of a stranded vessel "breaking "up" or going to pieces. Such cutting-under action of the sea may be compared to taking out part of the foundation of a house, and by thus leaving it but partially supported, cause it to tumble down. Sometimes the sea will cut under amidships,

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but more generally under her ends, causing a vessel to double up and then to break away. I may confidently say that during my intercourse with wreckers in different parts of the world I have never heard of any attempt being made to prevent this cutting under, nor have I ever seen any record of its having been attempted; most probably because no practical means has yet been proposed to meet the difficulty. Sometimes a sand-stranded vessel will lie perfectly easy on the beach many weeks; when a storm or gale sets the sea running, she cuts under and quickly breaks up. It is evident the only way to protect a vessel in such a position is by a breakwater or bulkhead so placed about her as to impede the current or turn it aside; one or more of these open-bottom pontoons is the only practical and effectual means of accomplishing this purpose, as when the tide gives evidence of probably cutting under, a pontoon may be sucked into the sand, leaving several feet protruding above it, and be thus made to act as a breakwater. As regards the power of such pontoons for holding on in a sea-way or current, so little as a half-pound vacuum will give them a grip of many tons force, according to the area of their top; but when their sides are once fairly embedded in the sand, they become immovable, independent of vacuum. As it may not seem clear how a vacuum is to be got in a pontoon totally submerged, it is well to state that if the water in the hose above the pontoon, and working it, has 1 foot less height of water in it than the altitude of the water outside it, and over the pontoon, the effect of a 1-foot vacuum is accomplished.

As the quickest way of getting a stranded vessel off is to lift or lighten her, the pontoons are arranged on each side for this purpose, in which position they also act as a breakwater. As their lifting power is equal to the displacement of the water they affect, the draught of a stranded vessel may be readily reduced one-half, three-quarters, or more, which fact will invariably ensure quick flotation. Another important fact in connection with these pontoons is, that when a vessel is inclined to sand up, they may be made to entirely obviate it, by continually keeping the pumps throwing air into them, which escapes under their lower edges into the sand, and keeps it stirred up, so that the wash of the sea carries it off—which act may even be made to produce a hollow sufficient for the vessel to float in, and so gradually work her seaward. This action may also be assisted by the tubes used for chaining being passed under her, as before described; but in case a vessel is very badly stranded, and it is preferred to wait for a high tide to roll in, in order to float her, the pontoons may be arranged and securely embedded about her, ready to be inflated as soon as the proper height of tide rolls in; for such purpose they are perfectly safe, and able to stand any sea unaffected.

In working the pontoons it is desirable, though not necessary, that a quantity of highly-compressed air be stored up in a reservoir, to be turned into them when

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wanted; and as thirty times the quantity of compressed air will pass through the same size tube than water (time and pressure being equal), prompt action is insured, with no risk of snapping the chains by sudden jerks, the air acting on them as an expansion cushion, and when once taut they will remain so.

On reef work a vessel may be lifted or lightened to the extent of 600 to 1,200 tons in a couple of hours after the pontoons are run alongside, attached and inflated. Of course not much can be done in bad weather on reef work, but it must be remembered that bad weather represents but a small portion of time, and reef work is susceptible of being quickly done, when all is at hand. The pontoons have no bottoms to be knocked in or injured by reefs or rocks, and are not subject to the undulations of the wave line as surface buoyancy.

The greatest strain to which these pontoons are subjected being tensile, and that of limited amount, the amount of bracing requisite is small.

DISCUSSION.

The CHAIRMAN (Sir F. W. E. Nicolson): As our time is getting short, I will propose that the usual vote of thanks be given to the author of the Paper. I almost felt tempted to say a few words about raising vessels; but as the vessels that have been raised, that I know something of, have only been in the Thames, and as the author at once acknowledges that the old-fashioned and rough-and-ready way is, perhaps, the best for smooth water, I need not say anything about it. I think he takes a very sanguine view of the probability of raising vessels in rough and deep water. He does not say his suggestions have ever been tried. Of course any person who can devise a means of raising vessels in deep water and in a rough sea will confer a great boon upon the world at large. I am very sorry to say that collisions between steamers seem to increase, and they have a great knack of going to the bottom at once, which the good old-fashioned wooden ships would not do.

Mr. HENRY LIGGINS: Will you allow me just to draw attention to a fact which will be in the recollection of many gentlemen here. Really, the matter comes so suddenly before me that I have forgotten the name of the ship to which I am alluding—I think it was the *London;* but it occurred a few years ago at Tayport, at the entrance to the river that runs up to Dundee. Admiral Sir Henry Keppel and Mr. Page, the engineer of Westminster Bridge, devised a scheme for pumping air into that vessel; but, after many weeks of work on her, they found it utterly impossible to make her air-tight, though she was partly out of the water at low water. There were so many cocks, scuttles, and hatchways, that, although they succeeded in stopping those parts that were easy to reach, they found it utterly impossible to make her air-tight; and therefore they could not pump their compressed air into her.

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After trying for many weeks, and spending a large sum of money, the affair was abandoned; when an old-fashioned shipwright—an old-fashioned man, from a yard in Dundee—thought of an old-fashioned plan of raising her, which if adopted he thought would possibly get her up. He was supplied with some money, and allowed to make the attempt, and in less than a week the vessel was afloat and in the dry dock at Dundee.

Admiral J. H. SELWYN: There is a statement in the Paper (*see* p. 197) which I do not think anybody here understands, with regard to vessels:—"As it may not seem clear how a vacuum is to be got in a "pontoon totally submerged, it is well to state that if the water in the hose above the pontoon, and "working it, has 1 foot less height of water in it than the altitude of the water outside it, and over the "pontoon, the effect of a 1-foot vacuum is accomplished." I confess I am utterly unable to see how that is proposed to be done. It is given as an explanation, and I think if the author could be induced to explain it, it would be desirable.

The CHAIRMAN: Unfortunately the author is not here, and it is not part of my duty, happily, to explain the author's meaning.

[With regard to this the following explanation has been received from the author:—

The statement which Admiral J. H. Selwyn refers to, is really somewhat ambiguous as it reads, but that paragraph suggested itself to me by the fact, that objections had frequently been made that water could not be raised over 32 feet by suction: this is so when raising it above the surface of water, but it may be raised from any depth below the surface by reason of the surrounding pressure; without the aid of this surrounding pressure water could not be raised by suction at all in any position or condition. The word "vacuum," in the paragraph referred to, is unfortunately used in a general sense (in order to avoid verbosity) and not in a scientific sense, as it is clearly impossible to get a vacuum in an open-bottom pontoon; but its internal pressure may be reduced more or less below its external pressure when its open bottom is sealed, or partially sealed, in the sand; and the result is that the pontoon is forced deeper into the sand, as the tendency of nature is to equalize pressures, and consequently the pontoon sinks into the sand as the handiest means nature has of avoiding a vacuum, or meeting any tendency thereto: but a vacuum itself is never got, and if it could be got would undoubtedly nullify the value of the pontoons, as when they are sucked into the sand they are necessarily filled with it to their tops, thereby anchoring them immovably. In answer to the Chairman's remarks about the apparatus being tried, I would say that the chaining part has been handily and satisfactorily done on vessels buried several feet in the sand, and in up to 30 feet of water. A pontoon having a capacity of 10 tons has been most satisfactorily operated on in the sand to show its facility for sinking, &c., but no regular organization has yet been formed for working the entire apparatus, owing partially to the circumstance that the inventor has been profitably engaged in another business which he cannot well neglect, together with the fact that through the universal commercial depression that has been ruling for the past two years it is difficult to get up an organization to work the apparatus properly; besides which all radical changes in an art seem to require a long consideration on the part of the public before being acceptable to their patronage. The publicity given to the system and apparatus by your Institution is certainly most valuable in revealing its merits and demerits, and it must now depend on its intrinsic worth alone and not on any further efforts of mine for its introduction.]

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ON THE TELEGRAPH CABLE SHIP "FARADAY."*

By C. W. MERRIFIELD, Esq., F.R.S., Associate Member of Council.

[Read at the Seventeenth Session of the Institution of Naval Architects, 7th April, 1876; Vice-Admiral Sir F. W. E. NICOLSON, Bart., C.B., Vice-President, in the Chair.]

IT occurred to me that some account of this vessel and of her performance ought to be given to the Institution, and I have therefore, through the kindness of Messrs. Siemens, obtained such particulars as I thought would be of most interest. Her builders were Messrs. Mitchell and Co., of Newcastle-on-Tyne. These gentlemen designed her, so far as regards all details of naval architecture and construction. The special fittings relating to telegraph work were arranged by Messrs. Siemens, and the bilge keels are due to Mr. Froude. You will see by the model and drawings before you what her general construction is—a double-ended ship with a rudder at each end, 360 feet long, 52 feet beam, and 36 feet deep, drawing usually at load draught from 22 feet to 24 feet. She has a flat floor, rather square bilges, with large external bilge keels, and is usually sailed on very nearly even keel. The vessel has three cable tanks, having an aggregate capacity of 109,500 cubic feet exclusive of the central cones. The form and displacement is such that the vessel will carry 4,300 tons of cable and water in tanks, 150 tons of stores and cable machinery, and 1,400 tons of fuel, or a total of 5,850 tons dead weight, all told, at about 26 feet mean draught of water.

GENERAL DESCRIPTION.

The hull of the vessel is built in accordance with Lloyd's Rules to the highest classification, namely, 100 A1. In addition to Lloyd's ordinary requirements, the vessel is further strengthened by having the upper and middle decks of iron from stem to stern, and the lower or orlop decks also of iron from the boiler room to foremast; the upper deck is also covered with pine planks; the main deck in the parts occupied by cabins is covered with wood. The construction of the tanks, iron decks, hull, inner

* Received 7th April, 1876.

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bottom, &c., is all so incorporated together as to give the greatest amount of mutual support and strength of structure, which has further been attained by having the double bottom carried on numerous longitudinal girders for the length shown on Plate XV. The space between the bottoms and up to second lower deck has been made available for water ballast. Length on water-line, 360 feet; breadth of beam, 52 feet; depth moulded, 36 feet. The vessel is fitted with two rudders, so that she may be steered at either end. She is propelled by two distinct pairs of engines and two screw propellers. The engines are on the compound surface-condensing principle, with a view to economy of fuel.

Cable Tanks are of the following dimensions:—Fore tank 37 feet diameter by 29 feet deep; main tank 45 feet diameter by 29 feet deep; aft tank 45 feet diameter by 29 feet deep. The tanks are circular and entirely constructed of wrought iron plates $\frac{1}{2}$ inch thick. The entire inner surface of the tanks is flush riveted. The bottoms are formed by the inner bottom of the vessel, and the tops of the tanks are united to the upper iron deck and also firmly united to the middle and lower iron decks. Each tank is provided with a centre water-tight cone for the proper stowage of the cables, which cones are made in pieces, connected together and to the inner bottom by bolts and india-rubber packing, so that they can be removed when required. The tanks are also provided with a proper system of cocks and pipes, and with a special steam engine for flooding the cable with water and for pumping out when required. A perforated rose extends a certain distance up each side of the cones, with a bent plate over the same to insure the water-tightness of the cones.

Water Service Pipe.—A wrought-iron pipe is carried from the engine room along the bulwarks, with brass nozzles placed at convenient distances, so that hoses can be attached for saturating the cables, washing decks, or other general purposes.

Water Ballast.—The space between the outer and inner bottoms of the vessel has been fitted to carry water ballast, and is divided transversely into three compartments, besides a longitudinal division, making six compartments in all, so that the vessel can be trimmed. The inner bottom is made of plating $\frac{1}{2}$ inch thick and carefully united to the skin of the vessel; one of the lower decks is made water-tight to form the upper part of the ballast compartments. They have all needful cocks and pipes for filling and emptying the various compartments independently of each other. They have also man-holes at convenient distances for cleaning, &c.

Rudders and Steering Gear.—The stem and stern-posts of the vessel are formed in such a manner as to receive a rudder at each end of the vessel, as shown on Plate XIV.

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The steering gear is of ample power, and is placed fore and aft in such a manner on deck that the ship can be steered at either end. A steam steering apparatus is supplied for working either the fore or after gear. The rudder not in use locks, by means of a vertical bolt dropping through the skin of the ship, into the shoulder of the rudder.

Coal Bunkers.—All available space in the engine and boiler room is arranged as permanent coal bunkers, with reserve supply arranged as conveniently as possible, making a total capacity of 1,400 tons.

Store Rooms are fitted up as shown on Plate XIV., and in such manner as the available space would permit.

Cabins are fitted up in the after part of the vessel, as shown in plan. The saloon has pilasters of polished wood with neat brackets at top, mahogany tables, swing-back seats, hanging trays for glasses, lamps, &c. The sleeping cabins are fitted with berths so constructed as to be easily removed for cleaning. Suitable accommodation has been provided for the cable hands and the crew of the vessel.

Testing Room is fitted up in the space between two cable tanks, as shown on Plate XIV., and has a strong table, battery, racks, writing desk, and other usual fittings.

Rigging.—The vessel is rigged as shown in Plate XIV. The lower masts are of iron, arranged to serve also for ventilation. All standing rigging is of galvanised wire rope and the running rigging of best Petersburg hemp. The sails are of navy canvas of suitable numbers.

Boats.—In number and size in accordance with the Board of Trade Regulations, and hung on iron davits. They are provided with rudders, tillers, oars, and boat covers complete. There is also a steam launch on board, and several American india-rubber rafts. The boats are slung with Hill and Clark's patent lowering apparatus. This apparatus has been very effectually tested on board the *Faraday*—much more so than it could possibly be on board ordinary trading ships. It is frequently necessary to lower boats two or three times a day, and that in heavy weather for many days in succession. In no one case, her captain says, has there been a failure. Moreover, when hooked again for hoisting up—which is done with great facility—they never unhook by a sea lifting the boat, as not unfrequently happens with common hooks.

Condenser, capable of supplying 500 gallons of fresh water per day, has been supplied and fitted.

Chain and Anchors, in size, numbers, and length in accordance with Lloyd's Rules.

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Windlass is on Harfield's patent principle, with brake and stoppers complete, and is worked by means of a special steam engine.

Awning.—The entire deck can be covered with canvas awning, carried on iron stanchions, with ridge ropes, &c., complete.

Steam Winches.—The vessel has three steam winches, with cylinders 7 inches in diameter and 12-inch stroke, and has a separate boiler for same, conveniently placed on deck on port side behind the galley.

Bilge Keels, 2 feet 3 inches deep, are fitted for about one-third of the vessel's length amidships, to prevent rolling.

Machinery.—The vessel is fitted with two pairs of compound surface-condensing engines, each pair arranged to drive an independent screw-propeller. Each pair of engines has a high-pressure cylinder, 39 inches diameter, and a low-pressure cylinder, 68 inches diameter; the stroke of piston in each case being 48 inches. The engines are on the inverted cylinder direct-acting principle, with horizontal surface condenser, arranged to support the cylinders at the back, the front part being carried on strong wrought-iron columns, to allow perfect freedom in getting at the various working parts of the engines. The starting and reversing gear are so arranged that the engines are under perfect control at all times; an auxiliary engine is fitted to work the gear. The screw-propellers are 16 feet diameter, with varying pitch. The propeller shafts, instead of being parallel, diverge as they go forward. The angle between them is not great, but it increases the leverage for turning, so that if the shafts were prolonged to the midship-section they would be then 40 feet apart. This arrangement was suggested by Dr. Siemens. It has been found of great service, giving a great addition to the manœuvring power of the ship, and enabling her to be held head to sea while at slow speed—say a knot an hour—while dragging for a cable. A Silver's marine governor is fitted to each pair of engines. A separate telegraph, with return signal, is fitted from the bridge to each pair of engines, also from the poop and top-gallant forecastle to engines, so that signals can be given by the officer in charge from all three places. There are six cylindrical multitubular boilers placed in such manner as is considered most convenient for trimming the coals. The vessel has two funnels; one placed on each side of centre line of vessel. The boilers have an aggregate heating surface of 9,000 square feet. They are constructed to bear a working pressure of 65 pounds on the square inch, and have been tested in accordance with the English Board of Trade Regulations. A steam pump, with cylinder 12 inches diameter by 12-inch stroke, has been fitted and arranged to work two double-acting pumps, for discharging water ballast

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and for filling and emptying the cable tanks, with proper valve boxes and pipes to work each independently.

The excellent performance of this ship, in executing the very special duty required of her, appears to me to justify a few further remarks. One of the most interesting features about her is her remarkable steadiness in a sea-way. She is not absolutely without rolling motion, but what she has is small in extent and very easy. It is hardly necessary to point out how essential this quality is for a vessel which has to lay and sometimes to pick up and underrun a telegraph cable. The means by which this quality has been secured in a vessel of 52-feet beam is worth noting.

In the first place, it is to be observed that she is of considerable depth in proportion to her beam, and that she is very square in the bilge. Considering her great breadth, therefore, she has rather a low metacentre. In the next place, whether at load or light draught, she carries her weight rather high, having her middle and upper decks both of iron, and some rather heavy machinery on deck. When fully laden with a large cable, this fills the circular tanks in which it is stored not very much below the line of the upper deck. When she is light, the increase of weight in the portion of her above the water-line is not much more than balanced by the water in her ballast tanks. The conditions all tend to easy rolling in a sea-way; but, considering her great breadth, would hardly secure this quality. A notable feature was therefore introduced by fitting her with two enormous bilge-keels, or false keels, outside the bilges, each 3 feet 3 inches deep, and about 120 feet long. These are made of sheet iron, and hollow—namely, two side plates, 2 feet 3 inches deep, and about 1 foot apart, secured to the side of the ship by angle irons, and closing together within about 3 inches at the outer edge of the bilge keel, where they are joined by a trough-shaped nose-piece, so as to give a face of about 4 inches broad to seaward. The effect of them is very strongly felt, not only in its general result of diminishing the amplitude of the ship's own roll, as distinguished from the forced roll due to the waves, but also, if one may venture to use such an expression, by anchoring her in the still water below, instead of allowing her to oscillate in obedience either to the surface motion or to the mean effective wave acting upon her side. This differential effect is a matter not of guess work, but of direct observation—the waves recoiling from her side in a very unusual manner, so that a boat lying alongside is forced away from her, even against the direction of the waves. This can only be explained by the reflex action of her straight side, and especially of her bilge pieces, on the circular motion of the water in the waves.

The researches of Rankine and of Froude, which are printed in our *Transactions*, have furnished the theoretical laws, by a judicious and reasonable application of which

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a successful result has been obtained in practice. It is not too much to say that those researches have given confidence to the designers of this large and therefore costly ship to go at once to the full development of those laws in her construction, instead of deferring their application through a long course of intermediate trials, which would have given us a series of vessels, each perhaps an improvement on its precursor, yet on the whole far less successful and more costly than the bolder measure of acting at once and fully on theories sufficiently well established to justify practical adoption. A little further popular elucidation of the general purposes of these theories may not be out of place. If we consider a cylinder floating in still water, so as to be exactly half immersed, and thus to have its axis in the water plane, and suppose it to be loaded either much or little below its centre of figure, then, if we set it rolling, it will oscillate exactly like a pendulum, and there will be nothing to stop it except the friction of the water on its surface. But for that it would go on for ever, with an unaltered oscillation, like a pendulum on frictionless bearings in a vacuum. If now we put a keel on this cylinder, we introduce a direct source of resistance to the oscillation, because the whole surface of the side of the keel has to be driven flatwise through the water as the cylinder rolls. The effect of this is not to alter, sensibly at least, the time of oscillation—that is to say, if it rolled ten times a minute without the keel it would still roll ten times a minute with the keel; but the extent of the roll would diminish very quickly, the rapidity of this diminution depending upon the size of the keel. So far as still water is concerned, any departure of the vessel from the half cylinder really acts as a keel and expends work in making waves, thus giving us a more or less rapid "curve of extinction," as Mr. Froude has called it.

In a sea-way the question is much more complicated, and it would be out of place here to attempt to trace the motion through all its phases. Moreover, it should be noticed that the problem to be solved is not to get rid of all motion, even of rolling motion. There would seldom be an advantage in having a vessel as still as a rock, and there would be many disadvantages about it. The one case in which it would be useful would be that of a cable ship; and even there the other disadvantages, which I need hardly enumerate to a nautical audience, would greatly overbalance the one benefit. What is really wanted is easy motion, such that the mere wind waves of the surface shall not sensibly affect, and such as shall be rather less than that of the longer swell frequently underrunning the wind waves. This easy motion is secured in the *Faraday*. Her great size and draught of water alone go a great way to secure her from the effect of any but very long waves, and her bilge keels, tending to make her conform to the further oscillations of the underswell, at a depth of 22 feet from the surface, give her all else that is needed.

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So much confusion of ideas prevails upon this question, that it may be worth while to repeat what has been many times stated in this room—that uneasy and inconvenient if not dangerous rolling depends not upon a ship rolling as much as, or even sometimes a little more than, the waves of long period which alone affect large ships, but upon accumulated rolling, where the times of the ship and of the waves harmonize with one another, so that every wave adds a little to every roll of the ship—just in the way that a slight motion of the wrist sends a sling whirling round and round. When a ship rolls rather more slowly than the waves, and with an inclination rather less than that of ordinary ground swell, that is all that is needed or that can usefully be sought for. She is then an easy ship, relative stillness being easier than absence of motion.

I am informed that the behaviour of the *Faraday* has been exceptionally satisfactory in this respect. Even in very severe weather it has been possible to pick up and underrun cables; there never has been any difficulty about paying-out from her, and none but the very worst weather has prevented such delicate operations as splicing, or has at all interfered with the observations in the testing room.

The vessel is not designed for great speed; that is not necessary for her work, and economy of coal consumption is far more to be thought of. Her ordinary working speed is from 8 to 9 knots, and she has exceeded 10 knots when under full steam.

I have not attempted to give you any account of the machinery special to the laying or picking up of the cables; that belongs to telegraphy rather than to naval architecture, and it is, moreover, a subject which I have not sufficient knowledge to venture upon.

DISCUSSION.

CHARLES W. SIEMENS, Esq., F.R.S., D.C.L.: As the owner and user of the steam-ship *Faraday*, I may be expected to make a few observations. First with regard to her construction. Our object was not to produce a ship of extraordinary dimensions, or of peculiarity of construction, but rather to accomplish an engineering object—that of laying a cable across the Atlantic on more advantageous terms than the *Great Eastern* would or could have done it. I may therefore say that this ship grew under our hands. The carrying capacity of the ship was given by the amount of cable which had to be carried. The questions then arose how to arrange this load in the ship and how to make the ship manageable under all circumstances. The Paper has stated already that the ship was constructed by Messrs. Mitchell, who have discharged their duty in a very perfect manner; and I should hardly have ventured upon so many points of novelty if I had not been supported by my friend Mr. Froude, who, as regards several of the details

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adopted, assisted us with his advice throughout. One of the difficulties in cable ships is that they roll enormously. It is true that the load is in large masses in the cable tanks and very low, but still that hardly seems to account for the tendency these ships have to roll. One of our objects was to make this ship free from that very great inconvenience, because in laying a cable, and still more in grappling for one and in splicing, the rolling motion is a very great evil. Mr. Froude suggested that there should be two enormous bilge keels instead of an ordinary keel to this ship, and the result has been very satisfactory indeed. But what is of still greater importance is that a cable ship should be able to be manœuvred in a way which is quite unnecessary in the case of ordinary mercantile ships; for not only has she to obey her helm very rapidly, but she has to remain in a certain position with her head to the wind perhaps for hours, and to go at a speed of perhaps one mile an hour only with a side wind upon her. Unless she is able to do this she is of no use for bringing up the end of a cable from the depths of the Atlantic except during exceptionally fine weather. With this ship we have accomplished the most delicate operations on the Atlantic when it was blowing almost a gale. The chief cause why she is so under command is the twin-screw arrangement. By turning one screw full speed forward and the other half speed backward, we hold the head of the ship up against the wind, and go slowly along dragging, or holding her in a position when we want to splice. But the ordinary twin-screw would hardly have been sufficient; we wanted greater force acting simply in order to tend to turn the ship; and then as the Paper states, it occurred to me to put the two propeller shafts at a certain angle to each other converging towards the stern. By this simple arrangement we get a distance between the two propeller shafts, if they were continued to the midship section, of some 40 or 45 feet; and that is the real angle and the real leverage with which we turn the ship, in turning the one screw forward and the other sternward. On making the trial on the open sea by throwing a barrel over the stern, we found that we could turn the ship round and round touching that same barrel again in eight minutes; so that we have a power there of turning the ship quite irrespective of her onward motion through the water.

Mr. J. Scott Russell, F.R.S.: Could you turn her standing in eight minutes?

Dr. Siemens: Yes.

The Chairman (Sir F. W. E. Nicolson): What you mean is, that you turn her without leaving the barrel?

Dr. Siemens: Yes; her stern would come back to the barrel, or nearly so, thus showing the turning power which we have. The only part of the ship which has given us some trouble is the rudder, or rather the two rudders. The forging, although very strong, has shown some sign of weakness, and one has been replaced; the other is about to be replaced by a stronger forging. But this very failure has given proof of the great manœuvring power which we possess in this ship. On the last occasion, when the cable had been ruptured, the rudder was in a somewhat shaky condition, and in going across the Atlantic it showed certain signs of weakness. It was thought prudent to lock the rudder, although the rudder was not disabled, and to manœuvre entirely by the propellers. We brought up the two ends of the cable where it had been ruptured in 100 fathoms of water, and laid the connecting bit, and made the splice while it was blowing very hard and the sea was very rough. I say that accomplishing all that without a rudder proves the advantage of the arrangement adopted. Then there is one other point of difference between this and an ordinary ship of that size, which is that it has a rudder at each end and has no stern. I was told that we should be pooped. An empty cable ship may be pooped if she lie

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still, trying to hold fast to the end of a cable; but it occurred to us that if we gave her no stern she could not very well be pooped, and the result has proved that she can lie in a sea-way without the least harm arising. On the whole I may say that the ship in actual work has proved a very thorough success.

The CHAIRMAN: Before you sit down would you inform us how many miles of cable you carried?

Dr. SIEMENS: 2,000 miles of Atlantic cable.

The CHAIRMAN: Was the bow rudder of any advantage?

Dr. SIEMENS: Occasionally it has been an advantage. If you had to take back a cable it would be an advantage to take it back by the same machine which paid it out previously, and in that case you would steer by the bow rudder. Another case where the bow rudder has been an advantage is in manœuvring the ship against the wind, because for turning it one way or the other you get an additional power of manœuvring.

The CHAIRMAN: But if you built another would you put a bow rudder to her?

Dr. SIEMENS: I think so.

Mr. CHARLES W. MERRIFIELD, F.R.S: The bow rudder in that case does not usually act as a bow rudder, but it is only when the ship has stern-way?

Dr. SIEMENS: Yes.

The CHAIRMAN: You alluded to the weakness of your stern rudder, but a weakness forward would, of course, be of still more importance. Of course one would not like to have a weak moveable joint in any part of a sea-going ship.

Dr. SIEMENS: We have never found any inconvenience from having a rudder there instead of a solid block.

The CHAIRMAN: That is what I wanted to ask.

Dr. SIEMENS: I may say the rudder is locked by a very strong bolt, which makes it actually like part of the ship: it goes in a frame.

Mr. BENJAMIN MARTELL: I am sure we must all feel obliged to Mr. Merrifield for reading this Paper, because the ship he has described is a remarkable ship, and is really a credit to the scientific knowledge and mechanical skill of this country. Why I particularly wish to say a word is because I think there is one point not alluded to, which I expected Mr. Merrifield would have noticed, and that was that this ship was built and fitted out in the remarkably short space of ten months, which is a most creditable thing for a ship of that size, and I do not know that it has been surpassed except by the same builders on a previous occasion. I think when we can turn out such a ship as that in ten months it reflects a great deal of credit on the mechanical skill of this country. I remember when the drawings of this vessel were brought to us, with a view to her being surveyed and classed in the highest class in Lloyd's Register, we saw that there were novel and striking features in the construction of the ship, and after looking at the special service for which she was intended, and at the various arrangements that had been entered into with a view to supplying adequate strength, when the ordinary mode of applying it could not be resorted to, we were satisfied that it was a most excellent structure, and that there would be no difficulty whatever in assigning her the highest class. You will see, if you notice the midship section, that there is this curious feature, you cannot see any beams across. There is a very large

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portion of the ship taken up by three large tanks in the middle, where it is impossible to get the transverse strength by beams placed across the ship in the usual way, and the consequence is that that transverse strength had to be afterwards supplied. Of course there were other practical considerations, and this is merely one of the questions which entered into the practical construction of the ship. When we consider the many good qualities which this ship was required to possess, and the various conditions; and when we consider the description of cargo which she had to carry, and the degree of stability required, which had not to be too much so as to make the ship roll uneasily, or too little so as to make her crank, —I think really the production of this ship altogether, from a mechanical and scientific point of view, has been a most creditable performance, and that it is but just to this Institution that the particulars of such a ship should be recorded in our *Transactions*.

Rear-Admiral ALGERNON F. R. DE HORSEY: There is a very interesting point connected with this ship which I should be glad if the author would be good enough to explain when he rises to reply. He has told us that the screw-shafts converge slightly, with a view to assisting the vessel to turn. The ordinary way of turning vessels with twin screws is this: You go ahead with the starboard screw, and go astern with the port screw, and then you expect her bow to turn to port; but it seems to me that going ahead with the starboard screw ought in this case to have the effect of turning her head to starboard. It may be that I am wrong, but if I am I daresay Mr. Merrifield will correct me. If the shaft points to the quarter it ought to have the effect of turning the bow in the opposite direction.

Dr. SIEMENS: Perhaps the gentleman does not rightly understand in which direction the shafts converge: the shafts converge towards the stern and not towards the bow.

The CHAIRMAN: I think Dr. Siemens explained that if they were continued as far as the midship section they would then be 40 feet apart, which is the lever.

Rear-Admiral DE HORSEY: Then it is my mistake.

Rear-Admiral J. H. SELWYN: It would be interesting if we learnt what useful effect has been obtained in this ship as compared with others. We see there screws in parallel lines. If there be anything in the question of the water coming more readily to the screw by reason of that convergence, it would be an interesting thing to know how far that operates in increasing the useful effect as compared with the indicated horse-power. I should like to ask Mr. Siemens whether he has observed at any time what was the nature of the cone of water thrown off from the screws, and how far they converged towards a point in the wake, instead of, as generally happens, diverging?

Dr. SIEMENS: I think the convergence of the screws tends to assist in the propelling power; the water flows more freely in the direction of the axis, and certainly the two vortices of water do converge, and they do form a more solid mass than probably would be the case if they were parallel; but of course it is very difficult to make comparisons between one ship and another, because there are so many conditions to be taken into consideration. But I think that whatever merit this has in it arises from the introduction of the converging screws: that is my impression.

Mr. HENRY FREDERICK SWAN: As one of the builders of the *Faraday*, I should just like to say that, having had the great responsibility thrown upon us, in connection with Messrs. Siemens and Mr. Froude, of designing that vessel, it certainly is an immense satisfaction to us to find how very well she has in every way fulfilled all that could have been expected of her. In designing a cable ship, as has been

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stated, there are enormous difficulties to encounter. It is not like any ordinary merchant vessel which has her cargo stowed on commencing her voyage, and which has to be discharged after her voyage is completed, and where you have only to take into consideration the difference of trim that will be caused by the amount of fuel burnt out. In a cable ship the weights and distribution of weights are ever varying, and in disposing of them it requires very great care and consideration so to place them as to cause the least amount of inconvenience in the protracted voyage necessary for performing such a service as laying an Atlantic cable. In designing the vessel also, as has been stated it was necessary to obtain great steadiness, and certainly the very valuable suggestions of Mr. Froude have turned out as successful as could possibly have been anticipated. I recollect well that Mr. Froude wished us to go even further with regard to the bilge keels than we felt justified in doing, and as far as my memory serves me he proposed that we should make them 4 feet deep. We rather demurred to that, as being far beyond anything that had been done, and eventually they were settled to be 2 feet 3 inches, which they were made. One of the objections to the depth would be their projection beyond the width of the vessel, and also beyond the line of bottom, which might be a source of great danger in shallow water, and also the difficulty that would be experienced in making them strong enough. Even with the depth of 2 feet 3 inches, notwithstanding the form in which they were made—a V form of double plate—we had, I must admit, a little doubt and uneasiness as to what the effect of that would be structurally; because, if these keels were to control that huge mass, we were afraid that the local effect of their mode of attachment to the hull might be a source of difficulty. However, I was very much pleased when I visited the vessel in dry dock after she had been to sea for a year, to find that not a rivet had started, and that there was no evidence whatever of any straining. The vessel as regards sea-going qualities and steadiness, is I believe as good as could possibly be expected, and as a rough way of illustrating this I may mention that after having gone through a very severe Atlantic gale, when she returned to this country the captain pointed in his cabin to the inkstand and other small articles standing on his table, and said, "There, you see those things; "they have passed through an Atlantic gale as they stand without being attached in any way." That very well conveys an idea of the steadiness of the vessel. I believe she has been under steam for a period of 120 days with the steam never off the boilers, and notwithstanding that severe test she has in every way fully answered Dr. Siemens' expectation.

Mr. Henry Liggins: I think it is very satisfactory indeed to hear such a high report of this ship. The subject of bilge pieces is one which many gentlemen in this room will remember I have brought under the notice of this Institution for many years past. I am surprised to find that one of the gentlemen concerned in building the *Faraday* should have had the slightest doubt about their efficacy, or about the ability of shipwrights to fix them sufficiently strong to resist every strain that they may be called upon to bear. I am sure that gentlemen will know very well the steamer I am about to mention, the *Tasmanian*, one of the West Indian Royal Mail Steam Packets, a vessel of the largest size—a screw steamer, and the most inveterate roller that was ever constructed in a shipwright's yard. Thirteen years ago it was determined either that that ship must be broken up as a vessel no passenger would travel in, or that her rolling propensities must be stopped. Some one suggested—certainly not Mr. Froude—that she should have two bilge pieces put on her somewhat similar to those that have been put upon the *Faraday*, and she has been running across the Atlantic between the West Indies and Southampton, with of course occasional dockages for repairs, from that day to this. That is some thirteen years ago. She is a very fine ship, and from being the horror of passengers whose names were unfortunately put down to be

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carried in her she has become quite a favourite vessel. I have many times, year after year, brought the matter before this Institution, and I am almost ashamed to mention it again; but I think it ought to be generally known throughout the length and breadth of the land that the bilge pieces have proved themselves to be a perfect success.

Mr. SWAN: Do you know the depth of the bilge pieces to which you have referred?

Mr. LIGGINS: I am sorry I cannot give the exact dimensions; I think they are under 3 feet.

Mr. MARTELL: I think they are 10 or 12 inches.

Mr. SWAN: Bilge keels of 10 or 12 inches are very ordinary things.

Mr. JOHN A. WELCH: Allow me to say a word upon this subject. The object of bilge pieces is not to prevent rolling, but to diminish it, and they have been successfully applied to this ship; but still there is a right and a wrong way of fitting them, and they have been variously fitted according as the ship has been in different hands. The way to look at a bilge piece being fitted is to conceive that it shall be a plane in the diagonal direction of which the trace shall be parallel to the water line you fix on as the medium draught line, and if you could conceive a door on its hinges of which the hinge portion is in the direction of the length, that would give you the exact direction to fit the bilge pieces. In that direction they will act with perfect success, but in any other direction they will have a retarding influence on the speed of the ship; so that you successfully carry out your object with respect to diminishing the roll, but at the same time you do not diminish the speed the ship may have to any great extent. A gentleman has alluded to the strength of the bilge pieces. They are generally fitted as temporary side keels, and the angle irons of the inner edge are generally tap riveted, so that in the event of their coming in contact with anything they can be removed from the side of the ship without causing any danger to the ship. When you come to any great depth—even 2 feet 3 inches—the proper thing to do would be to fit half-round iron on the outer edges, and by that means you would get a perfectly strong bilge piece.

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ON THREE-THROW CRANK ENGINES OF THE COMPOUND SYSTEM, CONSTRUCTED BY RAVENHILL, EASTONS & CO., LONDON, FOR H.M.S. *ROVER.**

By JOHN R. RAVENHILL, Esq., Member of Council.

[Read at the Seventeenth Session of the Institution of Naval Architects, 7th April, 1876; Vice-Admiral Sir F. W. E. NICOLSON, Bart., C.B., Vice-President, in the Chair.]

AT the Fifteenth Session of the Institution of Naval Architects, in the month of March, 1874, a Paper was read by Mr. G. B. Rennie on engines of the above description, at that time under course of construction by his firm for H.M.S. *Boadicea* and *Bacchante*, in which he brought under our notice a series of diagrams, showing the theoretical force exerted by the three cylinders at all parts of the path of the crank pin's centres in four different ways of setting the relative angles of the cranks, which he described as follows:—

No. 1.—With equal angles of 120° with each other.

No. 2.—The two low-pressure cranks, with 90° between them, and 135° between these and the high-pressure crank.

No. 3.—The low-pressure cranks, with the same angle between them, but at angles of 150° and 120° with the other one.

No. 4.—The low-pressure cranks placed opposite to each other, and at right angles to the high-pressure crank.

And he proceeded to give his reasons for concluding to adopt the position described in No. 4, the angles of the cranks of the two above-named ships.†

In the discussion that followed, I stated that in the three-cylinder compound engines then making by my late firm for the *Rover*, I had adopted the plan of placing the cranks at equal angles of 120° with each other (*see* Fig. 1, Plate XVI.), and promised to furnish the Institution with the practical result obtained, which I now propose to do; but prior to entering on this subject a short general description of the engines may prove interesting.

* Received 4th April, 1876. † *See* Diagrams Nos. 1 to 4, Fig. 1, Plate XX., Vol. XV. *Transactions* for 1874.

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As may be gathered from the heading of my Paper the engines have three cylinders, and they belong to the type known as the "Horizontal Return Connecting Rod," having their cylinder cross-bars working in slipper guides, and by the contract were to indicate 4,750 indicated horse-power at the measured-mile trial.

In their general design I followed, as far as circumstances would permit, our old well-known form of double-piston rod engine, such as had been made at Glass House Fields over a long series of years. Their main parts are shown in plan (*see* Plate XVI.)

The diameter of the high-pressure cylinder is 72 inches, representing an area of 4071·51 square inches of piston.

The diameter of the low-pressure cylinders is 88 inches, each of them having an area of 6082·13 square inches of piston; the two low-pressure pistons combined giving an aggregate area of 12164·26 square inches, the high and low-pressure pistons thus being a multiple of 1 to 2, 98 in effective area.

The high-pressure cylinder, which is fitted with a working barrel made of Sir Joseph Whitworth's patent compressed metal, is placed between the two low-pressure ones, and each cylinder stands separately and distinctly by itself, securely attached to its own two main frames, these latter six in all carrying the connecting shaft.

The slide valve of the high-pressure cylinder is placed on the upper side of it, and lies on its face. The slide face of the cylinder is cast separately, and bolted on to its place, with a view to its ready repair or renewal in case of need.

The slide valves of the low-pressure cylinders are placed on the sides of the latter, the slide faces of these cylinders being also bolted on, and all the slide valves are fitted with the usual metallic packing rings on their backs, to relieve the pressure. Steam starting gear, in addition to the ordinary hand gear, is fitted for the facility of handling them, and the easy way in which these large engines can be handled is best described by the results obtained.

Whilst running full speed ahead, they were stopped in nine seconds, went astern at full speed in six seconds, and were reversed from that position to full speed ahead again in eight seconds.

The casing of the high-pressure slide valve, to which the expansion valve casing is attached, is connected with the low-pressure slide valve casings by four copper pipes, A A A A, which are fitted as shown, through which the steam passes after leaving the high-pressure cylinder; and these pipes and the passages connected with them form the only steam reservoirs between the cylinders.

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The surface condensers are on Hall's system, the steam passing through the tubes standing on the opposite side of the connecting shaft to the cylinders, and each condenser is connected to its own low-pressure cylinder by an eduction pipe, through which the steam passes on leaving the latter, and have a total number of 7,724 brass tubes tinned inside and outside, giving a total surface of 9,500 square feet. The tubes are fitted in the tube plates with screwed glands and stuffing boxes, and the condensers are so arranged that they may be worked as common condensers if required.

The air pumps, double acting, are two in number, 23 inches diameter, with a stroke of 4 feet; and the circulating water through the condensers is driven by two centrifugal pumps worked by an independent pair of small engines, and the main suction pipes to these pumps are fitted with branch suctions leading into the bilges of the vessel, so as to become large bilge pumps in the event of any leak arising in the vessel.

There is the usual arrangement of feed and bilge pumps fitted on the main engines —two of each; they are of gun metal, and are 5 inches in diameter, with a stroke of 4 feet. In addition to these pumps there are two feed donkeys, a bilge donkey hand pump and fire engine, all fitted in accordance with the Admiralty specification.

The length of stroke of the engines is 4 feet, and the diameter of the connecting shafts is 18 inches, and of the crank pins 20 inches. The shaft is made in three pieces, having couplings forged on the ends, by which they are bolted securely together.

The diameter of the propeller shafting is $16\frac{1}{2}$ inches, and that of the stern shaft $18\frac{1}{2}$ inches, the latter running in the usual lignum vitæ bearings fitted in the stern tube, and the length of the connecting rod is twice the length of the stroke.

The screw-propeller is of gun-metal on the Hirsch principle, having a diameter of 21 feet, and is driven by an ordinary cheese coupling keyed on the stern shaft, and is fitted to lift in a banjo frame by means of sheer legs and tackle on deck.

The boilers which are ten in number stand athwartship in two groups. Each group of four and six respectively has its own separate chimney fitted on the telescopic principle, and the boilers carry a working pressure of 70 pounds to the square inch. They are about 11 feet 10 inches diameter, 9 feet 6 inches long, fitted with brass tubes of 3 inches outside diameter, and wrought-iron stay tubes. Each boiler has two furnaces, each 3 feet 10 inches in diameter, and 6 feet 8 inches long. The total heating surface of the boilers is 12,700 square feet, and the grate-bar surface is 510 square feet.

These engines were the first of their class to be tried, and as my connection with Messrs. Eastons & Anderson had ceased for some time prior to the 18th November, 1875, I had not the advantage of seeing them at work during the official trial, but in the Plate

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will be seen on a reduced scale copies of three sets of indicator figures taken during the above trial, which represent the average working performance of the engines; and we—this Institution as well as myself—are indebted to Mr. Wright, Engineer in Chief of the Admiralty, for supplying me with tracings of the original diagrams, and without which I could not have prepared this Paper. These diagrams also show the force exerted by the sum of the pressures of the three cylinders at all parts of the path of the crank pin's centre, set out from the pressures indicated on the diagrams, the proportion of the length of the connecting rod—*viz.:* four times the length of the crank—being duly taken into account.

The mean indicated horse-power exerted by the high-pressure cylinder during the six runs on the measured mile was 2476·6 horses, and by the two low-pressure cylinders combined 2486·9 horses.

The forward low-pressure cylinder giving a power of 1343·2 horses, and the after low-pressure cylinder 1143·7 horses. The mean pressure on the square inch in the three cylinders being as follows:—

High pressure ...	...	36·625 pounds per square inch.	
Forward low pressure ...		13·3	„ „
Aft ditto ditto	...	11·325	„ „

The theoretical action of the slide valves had been carefully gone into, and although of course this showed a difference in the two latter pressures, I was not prepared for the great difference shown in practice, and I am confident these pressures might be more nearly assimilated. But now that, for a time at all events, I have ceased to be a manufacturer of the marine steam engine, I shall watch with interest the record of the performances of the other three-throw crank engines at present being fitted on board vessels in Her Majesty's service, where different angles for the cranks will be tried to those I adopted in the engines of the *Rover*.

The sudden drop in the curve at *a*, is due in my opinion to the high-pressure slide valve closing the exhaust too quickly at one end of the cylinder, thereby causing an undue amount of compression as shown in the indicator diagrams of the high-pressure cylinder, but this could be easily improved the first time the slide is taken out of its casing.

Recent experience has demonstrated most clearly that we have closely approached, if we have not actually reached, the point at which the crank pins of large high-speed engines will work satisfactorily, in consequence of the very limited amount of bearing surface that of necessity can be allotted to them; and unless phosphor bronze should come to the assistance of the marine engineer, as white metal and lignum vitæ did in days gone by, it may be necessary to reduce the load on the high-pressure crank pins.

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Rather than depart from the angle of 120° for my cranks, I would alter the multiple of my cylinders; for with the three cranks set at equal angles to each other, you possess the great practical advantage of being able to work on with any two cylinders out of the three under many circumstances, in the event of temporary derangement with the third—an advantage that might prove to be the salvation of a ship and her crew on a lee shore, or in the time of war.

There are doubtless some amongst my audience who have only just commenced their career in connection with the marine steam engine, and they find large engines being constructed to work at a pressure of 70 pounds on the square inch, with a speed of piston of 560 feet per minute, and they perhaps scarcely realise to the full all the difficulties that arise in obtaining such high results.

I venture for one moment to draw their attention to what my own memory carries me back to, when I was in their position, some thirty-five years ago. At that time the Royal Mail Company's fleet was just commencing its service, and the wonders of the day then were large paddle-wheel beam engines, such as were constructed on the Thames, the Mersey, and the Clyde; those by Miller, Ravenhill & Co., constructed at Glass House Fields for the *Trent* and *Isis*, belonging to the above-named fleet, of 430 horses nominal power, cylinders 74 inches in diameter and 7-feet stroke, working collectively up to an indicated power of 770 horses, fitted with flue boilers, the safety valves being loaded to 4 pounds on the square inch, and the pistons travelling at 230 feet a minute. Compare such machinery with that I have been giving you a short outline of, and if progress so great has been made during the past, depend on it much more will be expected in the future.

In conclusion, there is one thing that requires the close attention of all those connected with marine engines. As a matter of absolute necessity in all high-pressure boilers for the Royal Navy, fitted with return tubes over the fire-places, the steam space above the water-line is very limited in its cubic contents, and the area of water level in this class of boilers is of necessity much contracted; and serious trouble when the boilers were being forced to their utmost has been experienced by the excessive priming that has taken place, and until the vessels have been at sea for some little time. There appears to be no known cure at the present time for this malady. The *Rover* was in this category after her official trial at the Maplin Sands; and although sent round to Portsmouth the priming became unmanageable, and she had to be sent to sea to overcome the difficulty. A Paper on this subject—*viz.*, "Priming in Marine "Boilers, its Causes and its Cure"—at some future time would prove extremely interesting to this Institution.

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DISCUSSION.

The CHAIRMAN: Mr. Rennie, whose name is mentioned in the Paper, is unable to come here to-night; but the Secretary will, in his absence, read a communication from him on the subject.

The following letter from Mr. Rennie was then read by the Secretary:—

London, 6th April, 1876.

To A. Sedgwick Woolley, Esq.,
Secretary Institution Naval Architects.

DEAR SIR,—I much regret that I shall not be able to be present to-morrow evening to hear and take part in the Discussion on the Paper on "Three-Throw Crank Engines, on the Compound System of H.M.S. *Rover*," by Mr. John R. Ravenhill; but as Mr. Ravenhill has been good enough to allow me to read a copy of his Paper, and as he has quoted the Paper I read before the Institution of Naval Architects in 1874, I beg to make a few remarks.

The engines of the *Rover*, as set forth in his Paper, have three cylinders, the cranks being placed at equal angles of 120° with each other—a position of cranks which I ventured to say was not advantageous for three-cylinder engines on the compound system; and if I rightly interpret the results and Mr. Ravenhill's remark upon the great difference of power in the two low-pressure cylinders of the *Rover*, he to a certain extent bears out my views, although he qualifies the remark by saying this could be improved by some alteration in the slide valves. My own impression is that no modification of the setting of the valves could make much difference, for the better the setting is made for one L.P. cylinder the worse it would be for the other; but where the arrangements of the engines will admit of it, an equality of power in the two L.P. cylinders, with their three cranks at 120°, may be obtained either by making a large reservoir or receptacle for the steam after leaving the H.P. cylinder of such a size that the pressure of steam therein would vary to a small extent; or, *secondly*, by having expansion valves to the low-pressure cylinders so as to cut off the steam not later than about $\frac{1}{3}$rd of the length of the stroke of piston. But the first method is practically impossible on account of the large space such a reservoir would take up in the ship; and the *second* method has the disadvantage of not getting the same amount of power out of a given quantity of steam, although there are advantages in getting uniformity of motion and equality of power in the three cylinders thus arranged; and I found this remark on the practical working of several engines where there have been means of cutting off the steam at different positions in the length of the stroke of the L.P. cylinder, the "cut-off" in the H.P. cylinder remaining constant. I have always found that an earlier "cut-off" in the L.P. cylinder correspondingly decreases the number of revolutions, although the same amount of steam is used in each revolution. The total horse-power is not only reduced each revolution but is likewise reduced by the fewer revolutions per minute; for although the mean pressure is increased in the L.P. cylinders, that in the H.P. cylinder is decreased in a higher ratio in consequence of the extra back pressure.

In conclusion I think Mr. Ravenhill is to be congratulated for the arrangement he has made, so that so large a power of engines as about 5,000 horses can be reversed in the short space of time mentioned in his Paper, and for his having obtained so near an equality between the powers of the H.P. cylinders and the two L.P. cylinders.

I am, yours faithfully,

GEORGE B. RENNIE.

Mr. JAMES WRIGHT: I had better, perhaps, commence the few remarks I have to make by stating the principal cause of three cylinders being specified instead of two as usual. The principal object was to keep the low-pressure cylinders within reasonable limits as regards their size. If they had been made in

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the usual way, with one low-pressure cylinder only, it would have been close under the deck beams; and we have had so much trouble before from cracks in very large cylinders, that we thought it desirable to adopt the plan of three cylinders, although perhaps on the whole they are a little heavier, than to trust to the one very large low-pressure cylinder. The subject of the best angle for three-cylinder compound engines is a matter that engineers seem to have great difficulty in making up their minds upon. In this country I think the setting, as in the case of the *Rover*, is preferred. Fig. 2, I think, is the plan adopted and preferred in France. In the Clyde a number of large three-cylinder engines have been made and have been working for some time, and very satisfactorily, with the cranks set at equal angles as in the *Rover*. Fig. 4 represents the engines of the *Boadicea*. In addition to these I have to name a fifth plan that is to be adopted in the large engines of the *Dreadnought* and the *Alexandra*, made by Messrs. Humphreys. In that case, taking the high-pressure cylinder crank as leading, the first low-pressure crank follows at an angle of 90 degrees; the second low-pressure crank follows at an angle of 135 degrees, that is to say the cranks are the same as in Fig. 2, except that the cylinders are differently arranged. That plan has the advantage that the low-pressure cylinders get the steam more nearly equal on the exhaust from the high-pressure cylinder, and the angles are also so nearly equal to those in the first plan that any two of the cylinders can be very well worked if the third should break down. With regard to the efficiency of the steam, I have had the whole of the diagrams of the full-power trial and the half-power trial of the *Rover* looked into, and I find that for equal weights of steam passing out of the low-pressure cylinders, the efficiency of the steam in the first low-pressure cylinder is 5½ per cent. more than the efficiency in the second low-pressure cylinder at full power; but at half power or low pressure the difference is very small, only about 1 per cent. That is in a great degree owing to there being no reservoir in the *Rover*. It was desired to save space and weight, and as you see there the exhaust pipes and the valve casings form the only reservoir that exists for these engines. Then with regard to the question of the endurance of crank pins which has been referred to by Mr. Ravenhill, that is one of the greatest difficulties we have to deal with in large engines; but he will be glad to hear that the largest set of engines made by his late Firm, *viz.*, the engines for the *Shah*, were tried yesterday at full power with phosphor bronze bushes at the connecting rod ends, and the engines developed nearly 7,500 indicated horses. The bushes were not altogether satisfactory, but they were an improvement upon the white metal in this respect; that, although they heated considerably, there was no running out of metal. With a little more experience in the use of phosphor bronze we may get over the difficulty as regards the crank pins. Then as to the question of priming I am not in a position to make any remarks at present, but some experiments are about to be made which I hope will throw some light on the subject, and by this time next year I may be in a position to say something more about it.

Mr. J. Scott Russell, F.R.S.: I am sure that this subject is so important that we cannot allow this valuable Paper to be read without getting all the good we can out of it. There is no doubt whatever that these diagrams do give us a very favourable account of the manner in which the pressure is here applied. At the same time we are obliged to say when we look down at the bottom—the sum total—in respect of equality of pressure, there is still a little margin left for improvement. But the practical questions that this raises are several—one of which evidently Mr. Ravenhill in this arrangement has completely solved. I do not think it would be easy to conceive a more compact, simple, efficacious, general arrangement than this appears to be. I think we must all agree to that. The difficulty about crank pins is a serious one. Perhaps you know I am a lover of three-cylinder engines—a very early

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lover—in fact, it was almost my first love. But the modern engine gives a great deal of trouble about crank pins, while in my particular favourite I get over the crank-pin difficulty by this arrangement. I put my three cylinders all on one crank, and to that one crank I give an enormous bush and bearing; and then I make the other fellows come outside and act as auxiliary. The consequence is I have an almost uniform pressure all round the bearings, and the sum total of three bearings in one. That is impossible here. You have here at least three separate cranks. Then comes the great difficulty—and the great difficulty to which I am afraid there is no solution—because there are several solutions each of which has its advantages and disadvantages. The great difficulty is in deciding at what particular angle to place your cranks. Now it is quite plain that if all the three cylinders worked exactly alike, as they did in my original pet engine, you have no choice. You have then only to put each of them at the angle of 120 degrees, and as to the other minor matters you let them work themselves out in the best way you can. Then comes Mr. Rennie's arrangement. I thought it was an extremely clever arrangement on the part of Mr. Rennie, by which he puts a couple of engines with two cranks at equal angles opposite each other. I need hardly say that the advantage of having two equal cranks opposite each other is that they balance their pressure, or nearly so—that is, if they are both on one plane. If the indications are different they do not of course. In my pet engine it is perfect; but in my friend's pet engine it is not. That being so, I was very much taken at first sight with the result of the arrangement, because when two cranks are in this position it happens that the diagrams of the indicator fit into each other so beautifully that it is very fascinating. This not being the case in regard to the cranks which are not on one and the same plane, then there comes an extremely difficult question about the angles. I am afraid we must say that the best arrangement is only to be got by such a compromise as Mr. Ravenhill has taken, because he says, "I will "take these angles of mine and then I will arrange the communications in such a manner that I get out "of them the most uniform pressure that is practicable." In like manner I have no doubt whatever that the introduction of the middle reservoir is a matter of great value. Therefore I think, summing up all these results, it appears that the arrangement which Mr. Ravenhill has taken possesses a great number of advantages on the whole. I hope very much that this system of high and low-pressure compound engines will be carried out even much further than it has been. I am pretty well acquainted with the manner in which it has been carried out by the French Government, and you may remember perhaps the beautiful engines of my friend Monsieur Dupuy De Lôme, in which three parallel cylinders, all of the same size, were made to work the same engine. He had the same thing in view as Mr. Ravenhill had, *viz.:* that if one cylinder is thrown out of use the two remaining cylinders, be they what they may, should be able in some manner or other to do the work of the engine. I think it is a great advantage of the three-cylinder engine that, when so arranged, if one of the three should be thrown out the two remaining ones might do the work. At all events, allow me to say to the young engineers present, that I think the endeavour of our principal engineers to obtain the best possible three-cylinder marine engine is an example of ambition in the Profession which they may worthily follow, and I hope that the next generation will even excel our own in the perfection with which they carry their ideas into practice.

Mr. Mac Farlane Gray: I paid a good deal of attention to this subject many years ago, and have taken much trouble to make the thing plain to myself. I used different kinds of diagrams to those which Mr. Ravenhill has shown us. I made a circular diagram, or what I may call a clock-faced diagram, which showed the relation of one cylinder to another at different points of the stroke better than it is seen upon those diagrams. For instance, if we take Mr. Ravenhill's three-cylinder engines and

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draw a vertical line to represent the high-pressure cylinder, and divide around that circle as on a clock face, calling it by the hours of the day, then we have the high-pressure cylinder at the top of the stroke—say at one end of the stroke at noon; and then at two o'clock one of the low-pressure cylinders takes steam; at four o'clock the other low-pressure cylinder takes steam; at six o'clock the high-pressure cylinder is at the other end of its stroke. At eight o'clock the first of the low-pressure cylinders takes steam again; and then at ten o'clock the next one,—now we see that the high-pressure cylinder exhausts at five o'clock and exhausts again at eleven o'clock. The first low-pressure cylinder takes its steam at two o'clock, three hours afterwards; the next one takes its steam at four, five hours afterwards; and the one low-pressure cylinder is always two hours off the steam before the other one opens at all, and gets the best of it. There is only one crank in each engine shown in the diagram. In considering the action of the steam we must remember that the piston has two sides and we might continue the crank to the other side. It acts the same on both sides of the circle, and I think if the diagram had been shown so none of us would have been surprised to have found that there was that difference between these two cylinders. Then with reference to the uniformity of pressure I would like to ask if the *vis inertia* and *vis vitæ* of the parts have been taken into account, because it considerably alters the diagram of the uniformity of pressure tangentially?

Mr. RAVENHILL: I beg to tell Mr. Mac Farlane Gray that the curve has been set out from the sum of the pressures as shown by indicator diagrams, following the rule he will find laid down in the work published some years ago by Mr. Scott Russell on the Steam Engine. I thought it better to follow some well-known principle, and it has been long ago recognized that the plan adopted by Mr. Scott Russell meets the case. I regret very much that Mr. Rennie is not here to-night. I should like to have asked him to have followed this Paper next year with the practical results which he may obtain in the *Boadicea* and *Bacchante*. My impression is that he may and will show a better indicated performance with that arrangement of cranks; but with the engines disabled on a lee-shore give me the engines of the *Rover*. You must remember, all of you, that theory is one thing and practice another; and especially so where you are running with a piston speed such as there is in the *Rover*. All marine engineers know that with a two-cylinder engine, and the cranks at 90 degrees and the reservoir, you can get a very perfect and beautiful indicator card from the cylinder. I leave it for those who are to follow to see if they can produce an arrangement of cranks—or an arrangement of small reservoirs, if weight will permit—to obtain with the three-cylinder engines an equally good card as has hitherto been shown by the two-cylinder engine. If they do they will have made great progress.

Mr. J. SCOTT RUSSELL, F.R.S.: If you will allow me—even in breach of discipline—to supply an omission, I should be very much obliged. Mr. Mac Farlane Gray has mentioned a very important element in the question, which I did not venture to raise, but which was raised for me this morning by the very serious Discussion on the indicated power and useful effect of marine engines, as made the subject of experiment by Messrs. Denny and as eliminated by Mr. Froude. It is the critical point which Mr. Mac Farlane Gray touched upon just now. Has he taken into account the momentum of the parts of the engine? Now there was a most serious statement made to us this morning, as the result of careful experiment and calculation, that—somewhere or other, somehow or other—something like 30 per cent. or 40 per cent. of the indicated power of an engine is buried or lost. Now, what becomes of this buried power? It is said to-day to be lost. I seriously thought at the time when this came forward, and it is now confirmed by the suggestion of Mr. Mac Farlane Gray, that out of these indicator diagrams was left

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all consideration of the enormous momentum of the reciprocating parts of the engine in that short-stroke high-speed engine which is the modern screw engine. I would just ask the Members to tell me if they see their way out of it? I observe that on the first half of the stroke the indicator diagram tells you that this steam is giving out an enormous power, not only in doing work but as we know in striking a heavy piston. I would ask the gentlemen present whether they know any part of the performance of an indicator diagram which shows how or measures the manner in which any of this power is afterwards given out? I do not know. Perhaps some of you may tell me. If, as far as I see, there is no indication given on the diagram how this buried power is restored, then I think we have a place in which we can find out how it is that so much more of the power of a steam engine is swallowed up in the engine, according to the indicator diagram, than we can possibly believe it is in reality. I believe that in the second half of the stroke of a quick-driving engine, to which there is a large cylinder and heavy masses, a great deal of the power which is put into it in the shape of acceleration comes out of it in the shape of giving out power to the engine; and I do not think that that is recognised anywhere in the indicator diagrams.

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ON SOME PERFORMANCES OF THE SCREW-PROPELLER, AND CERTAIN PROPOSED SCHEMES FOR INCREASING ITS EFFICIENCY AND REDUCING ITS STRAINING EFFECTS UPON THE HULLS OF SHIPS.*

By Hamilton W. Pendred, Esq., C.E.

[Read at the Seventeenth Session of the Institution of Naval Architects, 7th April, 1876; Vice-Admiral Sir F. W. E. Nicolson, Bart., C.B., Vice-President, in the Chair.]

The subject matter of the present Paper is divided into three heads, namely: first, a statement of the respective performances of screw-propellers of different shapes, and called individually after their respective inventors or designers; secondly, a general descriptive review of some novelties invented by various engineers in connection with screw machinery, each contrived by its originator either to fulfil in a better manner some functions already performed by other means in an imperfect fashion, or else to improve the working and increase the durability of existing machinery; and lastly, a consideration, in connection with the other two heads, of the straining injury done to the hulls of steam ships by their machinery, when the power of the latter is great in proportion to the displacement of the former; the fracture of shafts, and what means yield the best promise of mitigating such evils.

In putting before the Members certain particulars of the performance of screw-propellers, the author has to comment on the great obstacles the collector of data on this subject encounters in his search. The patentees of propellers, one and all, unite in a complaint that the owners, companies, and others using this or that pattern, persistently decline to furnish any particulars of its performance. The only explanation the author can give as a reason for such secrecy is that probably an owner who has tried a new form of screw and found it a failure does not care to publish the fact that he has made a mistake; while, on the other hand, if the trial is successful he will not want a rival to hear of the good things he has got. Whatever the cause, however, the

* Received 28th February, 1876.

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fact remains, and it is one to be regretted, because it is by extended and systematic comparison of the performances of different forms of propeller under various conditions of working that alone we can hope to secure the best results.

It is impossible within the limits of a single Paper to consider at all exhaustively the process of development which the screw has undergone even during the last ten years, and the author hopes that this will exonerate him from the charge of dealing superficially with his subject. As a matter of course, the efficiency of the screw-propeller is perhaps the most important of all the questions bearing on the subject. In using the word "efficiency" the author desires to impress upon his audience that he does not do so to denote the relative merits of two different patterns or forms of screw, contrasted with each other *per se*, but as referable to their respective capabilities to utilise the power of the engines to the best advantage. Marine engineers know that little more than half the total indicated horse-power of the engines is absolutely available for the propulsion of the ship by means of the screw. The most accurate way to ascertain the actual amount of the indicated horse-power available for the propulsion of the ship is to measure the thrust of the screw-shaft in pounds, and this multiplied by the speed of the ship in feet per minute will give it. A very concise and practical method of estimating the efficiency either of screw or of machinery is generally adopted now both by owners and engine builders; it consists simply in gauging the number of knots a given set of boilers and machinery and a given type of propeller will drive a certain ship with a fixed number of tons of coal; the factor of time may or may not be introduced into the trial. The author will, however, remind his hearers that the smallest consumption of coal per horse-power is not a complete test in itself; the boilers and engines may be very economical, and the screw, either from inherent defects or from its ill adaptation to the hull and machinery, be very wasteful. A comparison between the consumption of fuel and what the author will call "thrust horse-power," he thinks would be a good test of economy, because it would at once show, if taken in conjunction with the indicated horse-power of the engines, the real quantity of fuel used to propel the ship and the quantity wasted in loss. Such a test has very seldom been applied to determine the efficiency of this or that propeller.

The engineer who has bestowed most attention on such tests is Mr. Isherwood, formerly chief of the engineering department of the United States Navy, and Tables I. and II. give general particulars of some experiments instituted by him in 1858 on some gunboats originally built for the British Government to attack the forts of Cronstadt during the last Russian war, but which were subsequently employed in Chinese waters. The Tables set forth the particulars of the boats and of their engines. Half the

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number of boats were engined by Maudslay, the remainder by Penn. The distribution of power was computed as follows:—First, the following deductions were made from the gross horse-power of the engines: (*a*) power to work engines and shafting, the remainder (*b*) being the nett power applied to the screw-shaft. Of this nett power, judged by Morin's experiments, 7·5 per cent. is first absorbed by the friction of the load, and this is additional to the friction of the engine itself, and is directly as the load or pressure under which the engine works. This being deducted, the residue is partly absorbed in overcoming the cohesive resistance of the water to the surface of the screw, sometimes erroneously called the friction of the water on the screw-blades; it is in the direct ratio of the surface and as the square of the velocity; it equals about 0·45 pounds per square foot with a velocity of 10 feet per second. This then, as well as the power required to overcome the cohesive resistance of the water to the screw surface, being deducted, the residue of the engine power is apportioned between that expended in the slip of the screw, the propulsion of the vessel, and the ratio of speed of ship to speed of vessel. The Tables I. and II. are compiled on this analysis; in both equal weights of steam and fuel were used, and the speed of Maudslay's boats was 8·38 knots and that of Penn's 8·26 knots. Efficiency of working as measured by fuel consumption was greatest in Maudslay's engines, but owing to the better utilization of the power by Penn's screw a gain of 8 per cent. of economy was realized as compared with Maudslay's. Penn's was the most wasteful engine, but the superiority of his screw more than compensated for this. Both boilers were alike.

Mr. Isherwood states that from his investigations he finds that the weight of steam required to propel a vessel at different rates of speed is always in a much lower ratio than the cubes of the speeds, but its real value is difficult to determine accurately. Table III. gives the results of some experiments made by Mr. Isherwood at Hong Kong, in 1858, with the British transport, *Sydney;* and Table IV. gives her performances as contrasted with those of her sister ships, the *Ireland* and *Scotland*, and the relative economical efficiency of application of power of each of the screws was—*Sydney*, 1·18; *Ireland*, 1·00; *Scotland*, 1·146. Table V. shows the relative performances of six different propellers tried by Mr. Isherwood on H.M.S. *Conflict.* One of the screws tried was Sir Thomas Mitchel's "Boomerang," so called from its resemblance to a weapon used by the Australian savages; its shape resembles that of a strip of paper first twisted in a spiral and then bent like the letter S. Table V. also gives the general dimensions of the screws, and these experiments are especially valuable because so many different forms of propeller were tried with one and the same hull and machinery; though, as all the propellers were of the two-bladed type, no knowledge is gained as to the performances of three or four-bladed screws. The

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dimensions of the ship were as in Table VI. The attention of all inventors dealing with the screw-propeller has been principally directed to two points—the one being to devise a propeller that will drive a ship at the greatest speed with a given power, and which shall also have good reversing or backing power, and give the ship also as straight a course as possible with the helm amidships; the other being the greatest reduction of vibration. No one has bestowed more attention to the study and improvement of screw propulsion than Mr. Robert Griffiths, and one of his earliest ideas was to find out what radius of circle on a screw disc was the limit of maximum efficiency. He experimented on the principle of filling up the central part of the screw with a spherical boss, making these bosses of different sizes or various proportionate diameters to that of the screw disc. The author need not dilate on this point as it is one familiar to his audience, suffice it to say that Mr. Griffiths found the best size of central sphere to be between one-third and one-fourth of the diameter of the screw. Next he dealt with the shape of the blades, and he found the best width for them just over the boss to be one-third the diameter of the screw, and at the outer extremities one-ninth thereof.

Mr. Griffiths's more recent experiments have been directed, not to the shape of the screw itself, but to the determination of the best way of feeding it with water. It is perfectly evident that the action of the screw in driving a ship forward depends on the relative resistance opposed by her hull and by the water to the screw; or, to put it in another way, it depends on the resistance opposed by the water to the movement of the hull in one direction and to the repelling action of the propeller on the water in the opposite one. If both were equal of course the ship if then at rest would remain so; as it is, her rate of speed is exactly that due to the difference between the two statical forces, namely, that opposed by the water to the hull, and that opposed by it to the screw. The density of the water is alike in both cases so long as the hull and screw are at rest, but is so no longer when screw and hull are moving onwards; then the case is quite different, for the water resistance to the hull increases rapidly while that opposed to the repellent action of the screw diminishes, because to some extent the screw is going away from the reaction of the water. Besides this too the rotation of the screw tends to a centrifugal action, and throws the water partly sideways, the power expended in doing so being totally wasted, as the repellent action of the screw should be only in a line with the vessel's keel; and the author is of opinion that if the actual longitudinal area of the blades of a screw equal say one-fourth of the disc area, that then one-fourth of the power of the screw is wasted in centrifugal action on the water, with the attendant evil that there is the less water left to be repelled backwards. Thus if we suppose, for sake of argument and illustration, that the screw of a ship of given size must repel or

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react on a thousand gallons of water per second to drive her at the speed of four knots an hour, but that only that quantity reaches the screw altogether, and that a fourth thereof is repelled sideways; then evidently so much the less remains for the screw to react upon in a line with the keel: nor does the evil stop here, but the radial water currents set up induced currents before and behind the screw, and it then moves in a less dense medium than does the hull. Some inventors have curved the screw blades in a forward direction and inwards in order to make them draw the water towards the centre instead of throwing it outwards, but the attendant advantages of this do not seem to have been great.

Mr. Griffiths, being impressed with the necessity of overcoming this evil, has recently been trying some experiments with certain contrivances which the author will treat of in the second part of this Paper under the head of novelties. He will conclude this part of his Paper by drawing attention to forms of propeller representing some of the best practice of the most eminent firms of marine engineers, and to the performance of the screws devised in the most recent times by private inventors.

Fig. 1 (Plate XVII.) illustrates a three-bladed screw fitted to H.M.S. *Lapwing*, by Messrs. Rennie: its diameter is 8 feet 6 inches, and the pitch varies from 9 feet 6 inches to 13 feet 6 inches: it is a fair example of a "Griffiths" three-bladed propeller. The indicated horse-power of the engines was 502.

Fig. 2 (Plate XVII.) is a double two-bladed "Mangin" screw, fitted to H.M.S. *Bullfinch;* it is 7 feet 3 inches diameter, of uniform pitch; indicated horse-power of the engines, 458·5. A more modern form of "Mangin" is shown in Fig. 3 (Plate XVII). The author is not in possession of any data of the performances of these propellers. A "Mangin" screw was officially tried, fitted to H.M.S. *Blanche*, in February, 1868. The screw was 14 feet 7 inches diameter; pitch of leading portion of blade, 15 feet 7 inches; ditto of trailing portion, 17 feet; mean length of blade on keel line, 12 feet. With full boiler power the screw made 88·5 revolutions per minute, the speed of the ship being 13·63 knots per hour. With half boiler power the speed was 11·78 knots. The use of full boiler power caused a violent thumping action on the ship's stern.

Fig. 4 (Plate XVII.) illustrates a six-bladed screw, 15 feet 9 inches diameter, and of a pitch varying from 17 feet 6 inches to 21 feet 6 inches, fitted to the Egyptian Government steamer *Charkieh*. It was supposed that by dividing the surface into several small parts or areas greater steadiness would result, but comparative trials between it and a three-bladed screw showed that little difference existed. The six-

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bladed screw was used from Malta to Alexandria, and the other from Venice to Alexandria. The hourly fuel consumption and mean speed in each case were as follow:—

S.S. Charkieh.

Kind of Screw.	Coal used per Hour.			Mean Speed.
	Cwts.	qrs.	lbs.	Knots.
Six-bladed	33	3	15	10·65
Three-bladed	34	0	9	10·69

Table VII. shows the comparative particulars of the performances of this vessel with the six-bladed propeller, and those of the mail steamer *Ruahine* with twin three-bladed screws. Fig. 5 (Plate XVII.) shows the screw of the latter.

Fig. 6 (Plate XVII.) shows a two-bladed "Griffiths" screw, same as fitted to H.M.S. *Lord Warden* and *Lord Clyde;* diameter, 23 feet; mean pitch, 23 feet 6 inches; indicated horse-power, 6,705; revolutions of screw, 63·3; speed of ship, 13·49; displacement, 9,000 tons. Table VIII. gives the relative performances of H.M.S. *Minotaur*, *Agincourt*, and *Bellerophon.*

Another form of screw to which the author would direct attention is the "Lowe "Vansittart," and Table IX. gives the performances of this as compared with a "Griffiths," both having been tested with the screw steamer *Scandinavian;* while Table X. gives results attained by it with H.M.S. *Druid.* The "Griffiths" four-bladed screw, used with the *Scandinavian*, is illustrated by Fig. 7 (Plate XVII.); and the "Vansittart" is illustrated by Fig. 8 (Plate XVII). With the former the speed was 11·75 knots, and with the latter 12 knots. The "Vansittart" screw had also four blades, and both were 25 feet pitch. Figs. 9 and 10 (Plate XVII.) respectively illustrate a common and a "Vansittart" propeller, comparatively tried with H.M. gunboat *Fancy*, in Stokes Bay; and Table XI. gives particulars of both performances.

Fig. 15 (Plate XVII.) shows Dr. Collis Browne's propeller, and trials made with it as contrasted with a "Griffiths" showed that it did as much with 60 pounds of coal as a "Griffiths" performed with 80 pounds burnt per hour.

Fig. 11 (Plate XVII.) shows a certain form of the "Hirsch" screw, and Fig. 12 (Plate XVII.) shows its expanded blade. A trial was made on the steam ship *Herder*, whose engines were 600 nominal horse-power, of both the "Hirsch" and the "Griffiths" propellers. The speed with the "Griffiths" screw was 11·48 knots an hour, and with the "Hirsch" it was 12·38 knots, or a gain of 0·9 of a knot with the same power.

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Table XII. gives comparative speeds attained by Government vessels fitted with Hirsch's and with other propellers. Table XIII. gives the same particulars of mercantile vessels similarly fitted. Table XIV. gives comparative statements of consumption of fuel. Table XV. is a time table of the steam ship *Adriatic*.

The following is an extract from the log-book of the steam ship *Memphis*, of the Kosmos Steam Ship Company, Hamburgh, returned by Captain Arnstadt. It shows the results of four complete voyages from Hamburgh to Callao and back; two with the ordinary, and two with the "Hirsch" propeller.

Description.	Total Distance run.	Time under Steam.	Average Distance run per Day.	Average Speed per Hour.	Coal Consumption.		
					Per complete Voyage.	Per Day.	Per 100 Knots run.
	Knots.	Days. Hours.	Knots.	Knots.	Tons.		Tons. Cwts. lbs.
Ordinary	44,429	221 20	200·28	8·345	2,882	12·991	6 9 82
Hirsch	44,297	210 0	210·93	8·789	2,535	12·071	5 14 50

The Captain also reported that there was an absence of vibration, and that the vessel steered better with the "Hirsch" than with the common screw.

Table XVI. gives various extracts of reports on the performances of the "Hirsch" propellers.

Passing from this the author now proceeds to the second part of his Paper, or that dealing with some novelties in connection with screw propulsion, foremost amongst which he places Mr. Griffiths's two proposals, namely, the enclosing of screws in tunnels or sheaths, and his proposed duplication of the machinery in halves, one being placed in the bows and the other retained in the present position at the stern of the vessel. With regard to the first of these proposals, the arguments advanced by Mr. Griffiths in favour of this arrangement are based to a great extent on the principles already adverted to by the author of this Paper in reference to the feeding of the screw with water. Mr. Griffiths avers that by confining the water in a tunnel with a bell mouth in advance, the water is drawn in a dense condition to and confined around the screw; and that no radial motion can be imparted to the water, all the force exerted by the screw is rendered repellent astern, and the result is that no waste of power takes place. He also claims that there is less air drawn to the screw, and that the vertical movement and frequent lifting of the screw above the waves does not denude the screw of water to the same extent as is the case with an unsheathed screw. Mr. Griffiths also claims that the

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sheathing of the screw is an advantage for war ships, as there is then less chance of the screw being fouled by rope ends or wreck. In support of the first of these claims—that of giving dense water supply—Mr. Griffiths points to the remarkable results he has attained with his models, and more recently with H.M.S. *Bruiser*.

In support of the second claim as to the duplicate machinery scheme, Mr. Griffiths argues that by its adoption the breakdown of one set will not so totally disable a ship as does the failure of the single set now relied on; that two screws, one at the bow and the other at the stern, would work to greater advantage, and give better results than a single one at either point; that the parts of each set of machinery would be smaller, lighter, cheaper, and handier than in the single arrangement; that, if both sets were made to standard gauges, then if one set did break down, or both sets in different parts, in some remote port far from the means of repair, the sound parts of the one could be used to replace the defective ones of the other, and the ship got home with one perfect set. In reply to these claims the author would observe, first, as regards the enclosure of the screw in a sheath, that he believes no data has yet been gathered as to its efficiency on ocean steamers during long voyages, and therefore no opinion can be expressed as to its utility either as an economiser of power, or its effect in preventing a screw racing when rolled clear of the sea.

As to the question of fouling a great deal of controversy exists—one party agreeing with Mr. Griffiths, while another avers that the sheath regarded from this point of view is an evil, because of the fact that if a screw does foul in it the mischief is nearly irremediable at sea, and would probably lead to the total disablement of the propeller.

Concerning Mr. Griffiths's duplicate scheme, the author ventures to observe that while breakdowns continue as apt to occur as they are at present, it would be well not to have "all the eggs in one basket," did not great objections exist to such an arrangement as the duplicate one; it would also be a great gain could the sizes of the parts—especially of the moving ones—of large marine engines be reduced; but so long as areas of pistons and shafts increase as the squares of their diameters, so long will Mr. Griffiths find it impossible to get as much power, other things being equal, out of two sets of machinery weighing respectively say 50 tons, as he will out of one set weighing 100 tons; to say nothing of the other evils of such a system, such as waste of space, the need for two engine rooms, stoke-holes and staffs, and two maintenance bills, besides the known evils in mechanical engineering of never getting as good results from divided powers as from united ones, and the bad principle of employing two pieces where one can be made to do. The author will presently describe, in the third part of his Paper, the method he would suggest to save weight and bulk in marine engines.

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Professor Lutschaunig, Professor of Naval Architecture to the Imperial Academy of Trieste, has invented a device for putting a screw in the rudder; but as he has already read a Paper on the subject himself before the Members of this Institute about three years ago, the author will not do more than direct attention to it as being to some extent a novelty.* Fig. 13 (Plate XVII.) shows a novelty of another kind, namely a device for feathering the blades of a screw from the engine room; it is the invention of Mr. R. R. Bevis, of Messrs. Laird's of Birkenhead. Its principal feature is that the aft portion of the shaft is made hollow, and within it is placed a rod, united at one end with rods connecting it with cranks on the shanks of the screw blades, which are socketed into the central boss; while the other end is united to a screwed collar movable on the shaft, and which as it is moved backwards or forwards "feathers" the screw blades. The invention has been successfully tried in Mr. Brassey's yacht, the *Kathleen*, and after twelve months' service was found in good order.

Another novelty is, or rather was, Messrs. Harland and Wolff's lowering gear, fitted to the White Star steamer, *Britannic;* but it has been or is being removed. Fig. 14 (Plate XVII.) illustrates what was its general arrangement. The object of the inventors was to secure a *deep* and *permanent* immersion of the propeller; and the author would here take occasion to impress upon everyone the expediency of not confounding the two expressions, because each defines conditions of working essentially different from those denoted by the other. The former deals alone with the density of the water around and the superimposed quantity of water above the screw; the latter treats solely of the alternate stripping and drowning of a screw by the pitching of the ship. The Harland gear was devised to secure the twofold advantage, but the inventors seem to have overlooked the fact that the thrust of an inclined shaft only represents the resultant of a vertical and of a horizontal strain, and that if the angle of inclination be taken at say one in five with the horizon, then but four-fifths of the screw power is available to propel the ship forwards, the other fifth being wasted in keeping the stern of the ship thrust out of the water. The arrangement consisted in setting the engine shaft on an incline and making the screw shaft a separate affair, it being united to the engine shaft by a somewhat peculiar "ball-and-socket" joint, the socket being on its outer surface (formed also as a ball), which swivelled in a fixed box or casing, secured to a stern-plate which kept out the sea. The outer end of the shaft, just behind the screw, had a vertical bar united to it, and this was united to a rack above, gearing into a pinion on whose axle a worm-wheel was secured, the worm of which was actuated by manual labour on deck, and by this means when the ship neared shallow water the screw was raised up above the level of the keel out of danger from the ground; while

* See *Transactions*, Vol. XV., p. 97.

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when fairly in deep water it was lowered down to its work. The author is not aware of the reason assigned for its removal.

Another novelty has been devised in screw machinery by Mr. John G. Winton of Portobello, Edinburgh, and one of its proposed uses was for ships going on expeditions into ice latitudes. The following is Mr. Winton's own description of it. He calls it "A means of lifting a screw shaft out of its bearings when a vessel is afloat." He says:—

"I have long considered the stern-tube of a screw steam ship both a crude and a "dangerous invention. In the event of the propeller shaft breaking at sea, a ready "means of replacing it with the spare shaft usually provided is a great desideratum. "A vessel so fitted carries the means within herself of replacing a screw-propeller, "even when she may be heavily laden and at sea; or when in some foreign port a "screw-propeller and shaft can be replaced without the aid of a dry dock,—thus "shipowners would not meet with such severe losses as they do by the detention of "their vessels. In the plan I propose the screw-shaft is raised at an angle by means of "a ball-and-socket joint of the hemp-packed description, fitted to the usual water-tight "bulkhead forward of the stern-post, the ball having the usual lignum vitæ bearings "and stuffing box as in ordinary stern-tubes. To carry out this plan the screw "aperture requires to be slightly altered. The stern-posts are curved with radii struck "from the centre of the ball and socket, a well being formed in the deck for lifting the "shaft out of its bearings. The forward stern-post is formed of two side plates forged "or riveted to the other stern-post and to the deck, and is fitted with a bearing, to the "cap of which is fitted the apparatus for raising the screw and shaft by steam power, "or in some instances by manual labour. There is likewise a well connecting the "stern-post with the water-tight bulkhead, having a trunk fitted on the top for slinging "the shaft in the act of lifting it out of the ship. Such are the leading features of the "scheme. In the event of requiring to take out the shaft, the box coupling inside of "the ship requires to be removed, then the shaft can be raised and the blades of the "propeller taken off. Prior to that a blind flange fitted with a pipe is slipped over "the end of the shaft, and follows up the shaft as it is drawn out of the stuffing box on "the ball-and-socket piece, and is secured with the same bolts. In fact, as the shaft is "drawn out this short pipe and blind flange are screwed up, and take the place of the "shaft in keeping the hemp packing intact. The ball in the socket is secured at the "angle of inclination, and remains so while the shaft is taken out and until it is "replaced. Temporary shackles are fitted to the well, and when the shaft is being "replaced it is lowered through their eyes, which easily guide it into the short tube, "the nuts on the blind flange being slackened; when the shaft is again embraced by the

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" packing, a small test tap on the blind flange is opened, and we presume no water or " but little will flow, and then we may say that the operation of taking out and replacing " the shaft has been successfully accomplished. I likewise propose for Arctic steam " vessels to enclose the well by means of an india-rubber sluice as it were, clamped to " the stern-post, with a valve fitted for letting the water in the well into the ship, and " which would be pumped overboard in the usual manner; by this means when the " propeller is lifted out the well would be quite dry and free from ice, so necessary in " these waters."—So far Mr. Winton.

The author was recently shown the propeller (not a screw, be it observed) illustrated by Fig. 16 (Plate XVII). It consists of an axle to be set vertically, and on which are two tee or cross-pieces, one of which is a box or casing containing certain gearing; at either end of the cross-pieces are bearings, and between each pair is placed a vane like the fly of the striking gear of a clock; on their axles are wheels gearing with the rest of the gear in the tee-piece, and the action of the gear is to feather the vanes as described above; the centre axle does not rotate; the tee-pieces, united by a slum, do so on it; but it can be shifted on deck so as to cause the feathering to move the ship ahead, astern, or to turn her on her centre. It seems rather like a toy, and though suitable perhaps for shallow river boats or smooth water work, is not the author thinks available for sea or ocean work.

The author now reaches the third part of his Paper, being its last section, namely, a consideration of the straining injury done to the hulls of screw steam ships of great power in proportion to their displacement; the fracture of shafts and propellers; and what means afford the best promise of mitigating such evils.

The straining of a hull and the fracture of machinery, where the latter is not due to bad workmanship or material, or to the presence of water in the cylinders, are alike results of a common cause or set of causes. No mechanical engineer, the author ventures to think, will deny that much of the straining of hulls and machinery is due to the use of reciprocating engines, as well as to the want of uniformity of the driving forces of the engines within with the resisting forces opposed by the water to the propeller without the ship. Screw engines also are often of very short stroke in proportion to their cylinder diameters, and such engines never work pleasantly, even at low speeds and where the moving parts are small and light. In the author's opinion the proper type of engine for screw propulsion would be a rotary one, could only a good and durable one be devised; failing this, however, a reciprocating one must be resorted to, and attention should be given to lessen its defects as much as may be. The author would advocate the use of high-speed single-cylinder engines of as long a stroke as possible. He is aware that the momentum of a light piston, &c., moving rapidly may be as great as that

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of a heavy one moving at low velocity; but the light one is more mobile, and presents less of the passive resistance ever present in great masses of metal: this is a point in favour of the light engine. Again, he ventures to think that more steadiness and less straining action would take place with four-bladed screws of fine pitch than with a smaller number of blades and a coarse pitch.

As to engine economy, there is no question as to the superior advantage of high-piston speeds, though the author would not rush to extremes. He considers also that high-speed engines could be got into much smaller space than the present enormous slow-speed ones occupy. Probably he will be asked how he would propose to get a high-speed engine for a vessel whose build was best suited to a somewhat coarse-pitched screw, and his reply is that, assuming that the form of the hull regulates the pitch of the propeller, he would gear his engines, not in the way they were geared in the infancy of screw propulsion when the engines ran slower than the screw; he would cause them to run faster than it. Should such an arrangement be found advantageous in other ways, the defects of toothed gear at this kind of work would be much less with the smaller wheel acting as driver than they were in the old days when the driver was the largest; and even that arrangement did not do so badly, for he was told not very long ago that the gear in the old *Great Western* was still as perfect as ever. The author thinks, too, that a scheme by which the cylinders would be set fore and aft, and driving the screw by bevel gear is at least worthy of thought, because such an arrangement would give room for long strokes, and the gear would allow of high speeds of piston. He is aware that these are startling proposals, but they are, he ventures to repeat, worthy of consideration. That we have marine screw machinery arranged at present in that close conformity with sound mechanical principles which operates to reduce strains and risk of breakdowns to the greatest extent possible the author declines to believe, being of opinion that there must be something wrong in the design and mode of working a system of machinery which resulted in the smashing of such a shaft as that of which the *Atrato* furnishes an example—one of many—and which is illustrated in Fig. 17 (Plate XVIII.) It gave way during that vessel's voyage from Plymouth, in October, 1872, when four days out on her way to Australia with emigrants on board. She had made a previous departure, but had to put back with her propeller broken, and the whole affair made such a stir on the subject of surveying machinery afloat that the Board of Trade sent a circular to all its surveyors, thirty-two in number, requesting them to forward to it, in a tabulated form, the rules they respectively adopted for calculating the diameters of screw-shafts. This Table can be seen in the printed Report of the Board of Trade, and it gives the names of thirty-eight ships, the names of the engine makers, diameters of cylinders, length of strokes, steam pressures, diameters of shafts abaft the cranks actually fitted

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and same as found by surveyor's rule. Some of these gentlemen used rules of their own, while of the remainder some used Rankine's, some Anderson's, and some Molesworth's Rules. Table XVII. gives a few examples selected from these.

The author ventures to think that all such rules are inapplicable to the special conditions under which screw shafts work, and he cites in support of his views that although a margin of from three to six times the computed engine strain is left before the breaking strain is reached, yet fractures do take place and often too in sound shafts. The fact is, that the rules used are based on *statical* tests, which are nearly useless where dynamical strains of great and constantly-varying magnitude are operating. He ventures to think, too, that the existing practice of taking a shaft whose diameter is so great in proportion to its length as to practically deprive it of all elasticity, and uniting to one end thereof engines exerting great power in a decidedly intermittent manner, and securing at its other extremity a contrivance for absorbing that power as transmitted to it by the shaft—the said contrivance being itself exposed to resistances varying from nothing, as when the screw is stripped, to some of magnitude enough to nearly overcome the engine power—is opposed to all good mechanical principles. Moreover, the evil is intensified by setting and securing the shaft, or iron column, in a series of bearings fastened in turn to the kelson frames of the ship, whose hull, especially in long narrow shallow vessels, is to all intents a girder, and one which deflects more or less as it strains in a sea-way, causing of course certain strains on the shaft which of themselves must tend to strain after crank pins and stern-tubes. The author ventures to think that as the strains to which screws and shafts are exposed are peculiarly great as well as variable in magnitude, proper expedients should be adopted to ease such strains as much as possible. If the present method of fitting screws and their shafts be examined, it will be found to present the only example in mechanics, either of nature or art, from which the characteristics of elasticity or flexibility are almost entirely absent; and the author is of opinion that here is a great defect, and he believes that the introduction of some flexible springiness, both in a torsional direction in the shaft, and in a longitudinal direction in the thrust-blocks, would ease strains, diminish dangers of broken screws and shafts, and enhance the speed of steam ships by giving the propeller some independent liberty to move without dragging the inertia, or opposing the momentum of the reciprocating parts of the engines. That the introduction of elasticity here would probably give greater speed of ship, with equal engine power, it is reasonable to assume, because sailors know that a boat's crew towing by means of an elastic hemp cable will move a ship much faster than it could by tugging at sweeps on board. Captains of sailing ships know that by slacking rigging and knocking out mast wedges they can sensibly increase a vessel's speed, because then as they say she can "work a bit."

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The Oxford and Cambridge boat race is not rowed with oars that are rigid and inflexible, they are made of ash because it is flexible as well as tough. As to hull straining, flexible machinery ought to save that, even as a person springing from a height to lower ground, lands not upon his heels but upon his toes. As a means of preventing or lessening the chances of fractures torsional elasticity ought to operate well, because it serves to divide the momentum strain of heavy reciprocating gear moving at great speed over a longer time than is the case where there is little or no flexure present; also the dividing of the screw shaft from the engine shaft would keep strains from the crank pins, whether those of thrust or those due to the "working" of the hull frames.

Figs. 18 and 19 (Plate XVIII.) illustrate some plans devised by the author to give torsional and thrust elasticity to shafts and thrust blocks. The torsional is provided in two or three ways, as shown on the diagrams; the best of which in his opinion is that shown by Fig. 18 (Plate XVIII.), where it will be seen that on the end of the screw shaft a disc is secured, having a number of notches in its periphery radiating from the centre. On the end of the engine shaft a similar disc is placed, but in such a manner that it can be shifted along its own shaft nearer to or further from the other disc. Into the radial notches a series of steel blades are put, forming a flexible cage of springs, and through these the rotative power of the engine is transmitted to the screw. The degree of torsional elasticity can be regulated by moving the disc on the engine shaft nearer to or further from the one on the screw shaft. In the same Fig. 18 may be seen the author's elastic thrust block. Its design consists in making the thrust block with side lugs, which move in guides TT, even as a piston-rod guide block moves. In the forward ends of the guides, spiral or other buffer springs S are placed; and plungers PP on the thrust block lugs, travel in the ends of the cylindrical casings enclosing the springs. The thrust of the propeller is transferred through these to the vessel's hull, and none of it can ever reach and strain the engine cranks; while, as the screw shaft is separate from the engine shaft, no straining of the ship's frame in a sea-way can exert so great an influence for evil, on either the crank or the screw shaft, as it does where both are in one rigid length. It being necessary to provide against recoil shocks from the thrust buffers, two air cylinders are bolted, one against the after end of each guide (*see* Fig. 18, Plate XVIII.), the "aft" ends of which are closed. In each works a piston, packed with a cup-leather in such a way that the pistons, being united by rods to the "lugs" of the thrust blocks, can move forward easily; but in the event of recoil the packing becomes air-tight, and an air cushion is at once interposed against the pistons, which prevents any shock. A cock in the end of each cylinder enables the engineer to regulate the amount of cushion.

Other methods of securing torsional elasticity by means of drag-links, made of spiral

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springs, or by crank pins bearing against cantilever springs, &c., are also shown in Fig. 20 (Plate XVIII.) Fig. 19 (Plate XVIII.) shows a simple method of providing torsional elasticity for the screw shafts of small vessels, such as yachts and steam launches. It consists of the introduction or interposition of a single broad steel blade some feet in length, between the screw shaft and the engine shaft. Thrust elasticity is provided for the same shaft by placing on the one portion of the screw shaft a square box within which is a buffer spring; the corresponding part of the other shaft is square in form, and fits easily in the box, and thrusts against the spring.

That the principle of the foregoing arrangements is sound and practicable has been already practically demonstrated under severe tests, though not exactly in this way nor in marine work. Mr. Jeremiah Head, of Middlesborough, invented and has successfully applied an arrangement for introducing torsional elasticity to prevent shock in reversing rolling mills. The arrangement is illustrated in Fig. 21 (Plate XVIII.), and consists in introducing cantilever springs whose inner ends are secured to a sleeve or box on the mill shaft, while their outer ends engage in projections on the fly-wheel. When the clutch is shifted to reverse the movement of the rolls the motion of the fly-wheel is imparted, not through stiff unyielding spokes but through flexible ones, which divide the strain over a longer period of time.

Fig. 22 (Plate XIX.) shows a shaft-coupling to reduce shocks, invented by Messrs. Frederick Varley and Edward Furness. It consists of a cylindrical box into which a species of piston is closely fitted, but free to move; one side of it is a simple plane surface which bears against any yielding or springy substance, such as india-rubber, or else against oil or water. Its other side is shaped as a spiral cam. The box in which it works is secured to one length of shafting, while the corresponding part of the other length is fitted with the boss, which has a projection whose extremity is also shaped as a spiral to fit that of the piston, and on which it bears; if excessive strain comes on the shaft the spiral faces slip, and the piston is forced against the oil, water, or india-rubber.

The author will now conclude his Paper with a few observations on the—he ventures to think—important question of the fracture of shafts and their repair while at sea, or in some remote port where no workshops exist where they can be replaced by others. He will commence by observing that in his opinion, as he has before remarked in this Paper, the formulæ usually made use of to estimate the strength of ordinary shafting is inapplicable to large propeller shafts, and he will proceed to explain how he would like, for example, to have his own torsionally flexible shaft tested. The only proper way to test any structure designed for certain work is to test it under conditions, and in as far as may be the same way that its strength will be tried

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in regular work; and forasmuch as the strains on propeller shafts are often sudden in action, are constantly varying in magnitude and direction, and are moreover exerted while the shafts are rotating at particular speeds, the same conditions should, as far as possible of attainment, be present in the trial tests, all such conditions being carefully noted. Fig. 23 (Plate XIX.) illustrates to a scale of about half size a machine designed by the author as the one by which he would desire to see the elastic shaft shown in Fig. 18 (Plate XVIII.) tested; it consists of a bed-plate A, on which are mounted certain bearings, carrying three separate lengths of shafting. On the length, B is placed at one end. The notched disc C being overhung, and this portion of the shaft being of some length and oval in cross section as shown at D, the disc rotates with the shaft, feathers being in the author's opinion too weak; the other end carries a fly-wheel of known weight and diameter as partly shown at E; there are also a fast and a loose belt pulley F and G to take the driving belt of the engine moving all. An outer bearing supports the extremity of this shaft; the second length H of shafting has also an overhung and oval length of shafting facing that on B; and thus the overhang needed for the flexible cage of blades is divided equally in two portions, and the discs C and C^1 being movable, the amount of torsional elasticity can be reduced to nothing if requisite by advancing the discs as near as possible to each other.

The other end of shaft H is also oval and overhung, and on it is placed a box or sleeve. The third length I of shaft has both its ends overhung and oval, that one facing H being provided with a loose sleeve J, which corresponds with another marked K on H, and a space of say two feet is left between the shaft ends, or it may be more. The other end of I is fitted with a sliding clutch L. M is a tank within which is a screw-propeller N, of a size to suit the power stored up in the momentum of the fly-wheel. The propeller is mounted on a shaft O, which passes through a stuffing box P, at one side of the tank, namely that next the vert of the machine, and has on its outer end a clutch to match that at L. The other end of this shaft is supported on a bracket Q, riveted on the inner side of the tank M. The blades of the propeller are not fastened to the boss by studs and nuts, but by bolts, which pass through the flanges R, and which can be changed at pleasure for others of a different diameter. Above the tank M another tank of somewhat greater capacity, but with its bottom some inches smaller both in length and width, should be placed, and which bottom should be in halves on hinges and so arranged that the drawing of a bolt would allow them to fall open, letting all the water contained in the upper fall into the lower one M in a second. To admit of the screw shaft O being drawn, and the screw lifted out for repairs, as well as at the same time to ensure that it would always centre truly with the other shafting, the bottom of the tank should have either four wheels S S, travelling on rails T, or else

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a pair of V runners on its bottom on which the tank could be drawn back and the shaft of the screw drawn out and the propeller removed for repairs when needful.

The tests should be conducted on two distinct bases, the one being to test and ascertain as exactly as possible the margin of safety gained by the elasticity of the cage of blades V V, and determine its true value in this respect to influence the torsional strains on a shaft—which would be found by placing the ends of a test piece W in the sleeves or boxes J and K, it being of known diameter. The screw clutch being out of gear and the screw at rest in its tank full of water, the highest point of the screw being submerged at least 2 feet, the fly-wheel should be caused to rotate at a particular number of revolutions per minute, the discs C C^{1} being set as near each other as possible; the driving belt should be then thrown out of gear, and the screw clutch thrown in as suddenly as possible, bringing the momentum of the fly-wheel to bear at once on the screw. Breaking pieces of different sizes in diameter but of equal length should be thus tested until a diameter was found which just barely resisted the test. Then a similar system should be pursued with the discs C C^{1} as far apart as possible, and allowing the greatest elasticity to operate; then the difference of breaking diameter between the two would go far to demonstrate the true value of the elastic cage. The author will not enlarge upon the details of calculating fly-wheel momentum, area of breaking or test piece, nor on the means by which the extent of torsional yield could be measured, though he has thought out these points; he will only observe that inasmuch as the force exerted by a moving body of certain weight and velocity on another and resisting body is calculable by the weight multiplied by the velocity of the former, and dividing the result by the time occupied by the latter in destroying the momentum of the moving force,—then the angle of resilience described by the advance of the driving disc C beyond the driven disc C^{1}, would in itself give a fairly approximate means of computing the time occupied by the flexible cage in transferring the strain to the screw. Thus, if the angle of resilience were 30° and the shaft were at the time rotating 180 times in a minute, or three times in a second, then 30° being the sixth part of a circle, evidently the time absorbed would be the eighteenth part of a second; and assuming that an ordinary screw shaft, without any torsion elasticity save that inherent in itself, would deflect to say an angle of 5°, or the thirty-sixth of a circle, then the time for absorbing the strain would be but one-sixth of that gained by the flexible cage, with a correspondingly destructive strain on shaft, propeller, engines and hull.

The same system should be pursued to test the value of torsional elasticity to preserve the propeller from fracture; bolts of different diameters should be successively tried for securing the blades under both rigid and flexible torsion. The tests should be all made, both by starting the screw suddenly from repose in its tank full of water, and

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also—in order to obtain as many of the conditions as possible of a screw first lifted out of the sea and then buried beneath it—the screw ought to be rotated rapidly in its tank when the latter was empty, the upper one being full; then the bolt should be suddenly drawn and the water let drop on the screw. The author did think of making the propeller to lift, by the introduction of a universal joint, out of the water; but then the water would leak out of the tank through the slit made for the shaft, unless special provision were made against it, which would be costly.

The author feels that the proposed plan of testing would not exactly correspond with the working conditions present in an ocean steamer, but still much light would be gained on the subject without the risks attending the trying of a new scheme in deep water, with lives and property at stake.

As regards shafts broken at sea, the author has often felt surprise at the want of enterprise displayed by marine engineers in not devising means for readily and quickly repairing them at sea—at least well enough to get the ship home, or to save salvage claims. One obstacle in particular to effecting such repairs exists in the use of circular shafts, which of course render it necessary to cut key-ways or other flat places on the broken ends, or else to drill a great hole through them to take a bolt; all necessary to enable the rotative power of the engines to reach the screw. The author ventures to say that in his opinion shafts ought to be made *oval* at all points save at journal necks; he would also place on each length of shaft, when being made, a loose sleeve (Fig. 24, Plate XIX.), then, if a fracture took place without distortion, this sleeve being run up to cover the break, the rotative strain would go through the sleeve; while if the fracture was distorted, even then the oval shaft could be better patched with drag links than could the round one. It was remarked to the author once that fractures often took place in the journal necks, where his loose sleeve could not be resorted to. He overcomes this difficulty by the arrangement shown in Fig. 25 (Plate XIX.): the shaft is oval throughout its entire length, and at the points where it must be supported by a bearing, a sleeve fitting the shaft nicely, and made of suitable sectional strength, and *turned circular on its outside* for working in a bearing, is placed at that point. Now the value of such a bearing is this,—so long as the shaft itself is sound no torsional strain whatever is put upon this sleeve bearing; but should the shaft fail within it, then the shaft being oval it cannot rotate within the sleeve, and the latter transmits the torsion past the fracture. Fig. 26 (Plate XIX.) illustrates a shaft-coupling for repairing shafts at sea, invented by Mr. John G. Winton, whose other invention has been already referred to. He proposes two different forms of coupling, the one resembling a coupling brought forward about two years ago by a Mr. Cromwell Varley, brother of the gentleman whose invention has been already referred to. It is in halves, and has to be bolted together,

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embracing the shaft so tightly as to take part of the torsional strain, while cupped set screws biting into the shaft take the rest. The second coupling is shown in Fig. 26 (Plate XIX.); it does not come in contact with the shaft at all, depending alone on the set screws.

The author thinks he cannot conclude his Paper better than by directing attention to Fig. 27 (Plate XIX.), which illustrates the repair of a shaft effected 1,500 miles from port, on board the *Ethiopia* during her voyage to New York last summer. The shaft was 15 inches in diameter, and the fracture was a simple diagonal one; the broken parts were raised by jack screws, the edges smoothed, and a 4-inch hole bored through the opposing portions, into which a bolt was tightly fitted. Four steel drivers, 4 inches long, $1\frac{1}{4}$ inch broad and $\frac{3}{4}$ inch thick, were sunk into the shaft, flush with its surface just across the line of fracture. The whole was then tightly clamped by hoops bolted on the shaft. The vessel prosecuted her voyage safely to New York, and was sent home for repairs, the shaft being considered reliable for the voyage. The repairs occupied eight and a half days, working night and day; of course this could not have been effected in heavy weather.

[TABLES.

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TABLE I.—ISHERWOOD'S EXPERIMENTS WITH BRITISH GUNBOATS.

Kind of Screw used: Two-bladed True Screw.

	Dimensions of Gunboats.			
	Nominal Horse-power.	Beam.	Length.	Draught.
(*a*)	40	22 ft.	109 ft. 10 in.	6 ft. 0 in.
(*b*)	60	22 „	100 „ 0 „	7 „ 6 „
(*c*)	80	22 „	125 „ 0 „	8 „ 0 „

Maudslay's Engines.

Type.	Diameter of Cylinder.	Stroke.	Indicated Horse-power.
Plain double-cylinder ...	15½ in.	18 in.	207·82

Maudslay's Screw.

Diameter.	Diameter of Boss.	Pitch.	Length in Axial Direction.	Area on Plane at Right Angles to Axis.
6 ft.	10 in.	8 ft.	16 in.	9·24 ft.

Speed of Vessel, 8·38 knots per hour.

Penn's Engines.

Type.	Diameter of Cylinder.	Diameter of Trunk.	Stroke.	Effective Diameter of Cylinder.	Indicated Horse-power.
Double-cylinder trunk	21 in.	11 in.	12 in.	17·8 in.	185·73

Penn's Screw.

Diameter.	Boss Diameter.	Pitch.	Length in Axial Direction.
6 ft.	10 in.	6 ft.	9 in.

Speed of Vessel, 8·26 knots per hour.

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Table II.—Analysis of Work done by Maudslay's Engines.

Speed of boats	8·38 knots.
Gross indicated horse-power	207·82 „
Pressure (mean) of steam on pistons per square inch	40 lbs.
Computed thrust of the screw	4,552 „

Distribution of the Power.

Power absorbed by engine and shafting	12·29
Net residue for screw shaft	194·83

This last is thus divided:

Absorbed by load friction	14·61, or 7·5	per cent.
„ cohesive water resistance	19·31, or 5·2	„
Absorbed in slip of screw	52·67, or 27·0	„
Balance for ship propulsion	117·24, or 60·0	„
Totals	194·83, or 100	„

Analysis of Work done by Penn's Engines.

Speed of boats	8·26
Per-centage of slip to speed	24·5
Gross indicated horse-power	185·73
Effective pressure of steam in cylinders per square inch	32·96 lbs.

Distribution of the Power.

Power taken by engines and shafting	14·9
Net residue for screw shaft	171·64 H.P., or 100 per cent.

This last is thus divided:

Absorbed by load friction, engine and shafting	12·87, or 7·50	per cent.
Absorbed by cohesive water resistance	10·03, or 5·84	„
Absorbed in slip of screw	36·44, or 21·23	„
Balance for ship propulsion	112·30, or 65·43	„
	171·64, or 100·00	„

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Table III.—The S.S. "Sydney."

Length of keel	209 ft.
Breadth of beam	33 ,,
Mean draught	16·35
Immersed cross section in square feet	450
Thrust of screw at a speed of 10 geographical miles per hour	17,740 lbs.

Particulars of Screw of S.S. "Sydney."

Kind of screw	Expanding pitch fore and aft.
Diameter	14 ft.
Diameter of boss	21 in.
Mean pitch from which slip was calculated	18 ft. 9 in.
Length in direction of axis	1 ft. 10½ in.
Gross indicated horse-power	8·36
Speed of ship per hour	8·69 knots.

Slip is not given.

Table IV.—Isherwood's Experiments with British Transports.

	Names of Vessels.		
	Sydney.	*Ireland.*	*Scotland.*
Diameter of screw	14·0	12·5	13·5
Pitch	18·75	21·0	17·5
Fraction of pitch used	⅕	⅓	¼
Helicoidal area	37·18	55·22	44·21
Per-centage of slip	13·08	21·05	14·16
Revolutions for equal speed	1·017	1·000	1·103
Cohesive resistance of water to the screw ...	1·00	1·23	1·32
Relative economical efficiency of application of power	1·18	1·00	1·14

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TABLE V.—ISHERWOOD'S EXPERIMENTS—H.M.S. "CONFLICT."

	KIND OF SCREW USED.	Diameter of Screw.	Pitch of Screw.	Speed per Minute. Revolutions.	Speed of Ships in Knots.	Slip.	Indicated Horse-power.
A	Common two-bladed screw	13·5	16·5	68·0	9·28	17·5	812
B	Ditto, corners rounded off ...	...	15·16	75·7	9·42	16·5	
C	Common two-bladed "Griffiths" ...	...	...	77·0	...	17·3	
D	Ditto, uniform pitch	...	19·85	62·0	9·63	22·4	
E	Is D reduced to equal area with F ...	...	...	65·87	9·50	25·59	
F	"Boomerang"—two blades ...	...	20·0	66·68	9·72	26·05	

TABLE VI.—THE S.S. "CONFLICT."

Length between perpendiculars	192 ft. 6 in.
Breadth, extreme	34 „ 4 „
Draught	14·5 „
Gross immersed mid-section in square feet	402
Resistance of hull at a speed of 9 geographical miles per hour ...	16,360 lbs.
Gross indicated horse-power	777·50

TABLE VII.—"CHARKIEH AND "RUAHINE."

Name of Ship.	Displacement in Tons.	Area of Midship Section in square feet.	Indicated Horse-power.	$\frac{\text{I.H.P.}}{\text{Area of Midship Section.}}$	$\frac{\text{Displacement in.}}{\text{I.H.P.}}$	Speed in Knots per Hour.	$\frac{\text{Area of Mid-section in square feet.}}{\text{Total Area of Propelling Surface in square feet.}}$	$\frac{\text{Speed} \times \text{Mid-section.}}{\text{I.H.P.}}$	$\frac{\text{Speed} \times \sqrt[3]{\text{Displacement.}}}{\text{I.H.P.}}$
Charkieh	2,200	462	1,475	3·192	1·491	11·4	8·105	45·930	169·19
Ruahine	1,850	424	1,540	3·632	1·2	13·0	10·408	604·88	215·4

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TABLE VIII.—"MINOTAUR," "AGINCOURT," AND "BELLEROPHON."

Name of Ship.	Displacement in Tons.	Area of Mid-section in square feet.	Indicated Horse-power.	$\frac{\text{I.H.P.}}{\text{Area of Mid-section in square feet.}}$	$\frac{\text{Displacement in Tons.}}{\text{I.H.P.}}$	Speed in Knots per Hour.	$\frac{\text{Area of Mid-section in square feet.}}{\text{Total Area of Propelling Surface in square feet.}}$	$\frac{\text{Speed} \times \text{Mid-section}}{\text{I.H.P.}}$	$\frac{\text{Speed} \times \sqrt[3]{\text{Displacement}^2}}{\text{I.H.P.}}$
H.M.S. *Minotaur* ...	10,275	1,322	6,193	4·684	1·659	14·16	9·713	606·71	216·616
H.M.S. *Agincourt* ...	9,000	1,187	6,867	5·785	1·310	15·43	8·600	635·38	231·242
H.M.S. *Bellerophon*	7,369	1,207	6,199	5·135	1·181	14·05	...	540·37	169·229

TABLE IX.—VANSITTART PROPELLER.

S.S. "Scandinavian," Liverpool to Montreal and back.—Registered Tonnage, 1811.

Nominal horse-power	400	400
Indicated ditto, average	1,800	1,800
Number of revolutions	54	47½
Steam pressure	30 lbs.	30 lbs.
Average speed, knots	11¾	12
Displacement	5,375 tons	5,375 tons
Diameter of propeller	18 ft.	18 ft.
Pitch of ditto	25 ft.	25 ft.
Description of ditto	Griffiths	Lowe-Vansittart
Number of blades, steel	4	4

TABLE X.—H.M.S. "DRUID," 350 HORSE-POWER.

Immersed mid-section, in square feet	413·3	413·3
Revolutions per minute, mean	96·8	95·03
Indicated horse-power	2373·74	2271·71
Speed of ship, knots	12·986	13·064
Speed 3 × mid-section, indicated horse-power ...	381·3	403·0
Description of propeller	Griffiths	Lowe-Vansittart
Slip per cent.	10·37	8·01
Number of blades	2	2, gun metal.

Place of trial, Maplin Sands, on measured mile, by order of the Admiralty, December, 1869.

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TABLE XI.—TRIAL OF H.M.S. "FANCY" WITH THE LOWE-VANSITTART PROPELLER,

Made on the 24th June, 1868, against the Common Screw manufactured by Messrs. Penn.

Description of propeller	Common screw in gun-metal	Lowe-Vansittart in iron
Where tried	Portsmouth	
Draught of water forward	6 ft. 8 in.	
„ „ aft	7 ft. 1 in.	
Area of mid-section, immersed	134 sq. ft.	
Steam pressure in boilers	40 lbs.	
Mean pressure in cylinders	35·39	37·69
Mean revolutions per minute	180·19	153·3
Indicated horse-power	194	176
Speed on measured mile, mean of 6 runs ...	7·9	7·9
Duty performed, or speed 3 × mid-section, indicated horse-power	347·5	377·8
Diameter of propeller	6 ft.	6 ft.
Pitch of ditto	6 ft.	7 ft. 1 in.
Remarks as to vibration	Considerable	Very slight

TABLE XII.—THE HIRSCH PATENT SCREW PROPELLER. COMPARATIVE SPEED.

Government Vessels.

Name of Vessel.	Name of Government.	Nominal Horse-power.	Description of Propeller.	Speed in Knots per Hour.	GAIN BY THE HIRSCH PROPELLER.
Crocodile ...	Royal British Navy ...	700	Griffiths	8·93	0·55
			Hirsch	9·48	
Sirius ... (sister ships) *Dido* ...	Royal British Navy ...	350	Griffiths	13·085	0·598
			Hirsch	13·683	
Louise	Imperial German Navy	400	Griffiths	13·37	0·70
			Hirsch	14·07	
Gunboat	Imperial Russian Navy	80	Ordinary	8·21	0·885
			Hirsch	9·095	

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TABLE XIII.—THE HIRSCH PATENT SCREW PROPELLER. COMPARATIVE SPEED.

Mercantile Marine.

Name of Vessel.	Nominal Horse-power.	Description of Propeller.	Speed in Knots per Hour.	GAIN BY THE HIRSCH PROPELLER.
Conrad	400	Griffiths	9·575	1·075
		Hirsch	10·65	
Conrad ... ... (sister ships) *Koning der Nederland*	400	Griffiths	9·575	6·625
		Hirsch	10·495	
Conrad ... ... (sister ships) *Prins Hendrik* ...	400	Griffiths	9·575	0·920
		Hirsch	10·495	
Herder	600	Griffiths	11·48	0·9
		Hirsch	12·38	
L'Isere	80	Ordinary	7·985	1·005
		Hirsch	8·99	
Louisiane	500	Ordinary	10·05	1.05
		Hirsch	11·10	
Memphis	150	Ordinary	8·345	·444
		Hirsch	8·789	
New Pelton	80	Vansittart	8·	1·25
		Hirsch	9.25	
Pereire	1,000	Griffiths	15·459	1·0
		Hirsch	14·459	
Sun-foo	180	Ordinary	10·5	0·75
		Hirsch	11·25	
Willem III. ... (sister ships) *Prins van Orange* ...	400	Ordinary	10·0	1·0
		Hirsch	11·0	

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TABLE XIV.—THE HIRSCH PATENT SCREW PROPELLER. COMPARATIVE CONSUMPTION OF COAL.

Name of Vessel.	Nominal Horse-power.	Description of Propeller.	Consumption of Coal. Per 100 Knots run. Tons.	cwts.	lbs.	Gain by the Hirsch Propeller. Tons.	cwts.	lbs.	Knots run on 100 Tons.	Gain by the Hirsch Propeller.
Conrad	400	Griffiths	11	3	65	0	18	3	894·51	78·45
		Hirsch	10	5	62				972·96	
Conrad ... ... (sister ships) *Koning der Nederland*	400	Griffiths	11	3	65	0	19	38	894·51	84·69
		Hirsch	10	4	27				979·20	
Conrad ... ... (sister ships) *Prins Hendrik* ...	400	Griffiths	11	3	65	0	15	69	894·51	67·16
		Hirsch	10	7	108				961·67	
L'Isere	80	Ordinary	4	11	12	0	10	65	2195·07	288·39
		Hirsch	4	0	59				2483·46	
Louisiane	500	Ordinary	23	6	35	2	10	110	428·89	52·65
		Hirsch	20	15	37				481·54	
New Pelton ...	80	Vansittart	6	15	46	1	2	90	1476·92	299·08
		Hirsch	5	12	68				1776·00	
Sun-foo	180	Ordinary	5	9	58	0	7	33	1826·08	130·44
		Hirsch	5	2	25				1956·52	
Willem III. ... (sister ships) *Prins van Orange* ...	400	Ordinary	9	12	96	0	15	107	1037·03	93·52
		Hirsch	8	16	101				1130·55	

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TABLE XV.—SHOWING COMPARATIVE DURATION OF TEN VOYAGES FROM QUEENSTOWN TO NEW YORK AND BACK WITH ORDINARY PROPELLER, AND TEN WITH HIRSCH'S PROPELLER.

S.S. "Adriatic."—White Star Line.

Left Queenstown.			Arrived at New York.			Left New York.			Arrived at Queenstown.			Duration of Complete Voyage.		
Date.	Hrs.	Min.	Date.	Hrs.	Min.	Date.	Hrs.	Min.	Date.	Hrs.	Min.	Days.	Hrs.	Min.
Oct. 9	8	0 p.m.	Oct. 18	4	50 p.m.	Oct. 28	9	50 p.m.	Nov. 5	12	30 p.m.	16	23	40
Dec. 18	11	45 a.m.	Dec. 28	11	0 p.m.	Jan. 10	10	20 a.m.	Jan. 18	5	10 p.m.	18	18	5
Feb. 5	8	40 p.m.	Feb. 15	2	0 p.m.	Feb. 28	10	0 a.m.	Mar. 8	4	0 a.m.	17	11	20
Mar. 19	3	58 p.m.	Mar. 28	8	0 p.m.	April 4	3	5 p.m.	April 12	11	5 a.m.	17	0	2
April 24	2	40 p.m.	May 3	11	40 a.m.	May 9	10	0 a.m.	May 17	12	0 a.m.	16	23	0
May 28	11	20 a.m.	June 5	9	0 a.m.	June 12	12	0 m.	June 20	9	34 p.m.	16	7	14
July 2	12	30 p.m.	July 11	4	0 a.m.	July 17	5	45 p.m.	July 22	7	15 p.m.	18	17	0
Aug. 6	10	40 a.m.	Aug. 14	4	30 p.m.	Aug. 21	8	0 a.m.	Aug. 29	10	32 p.m.	16	20	22
Sept. 17	10	0 a.m.	Sept. 25	9	30 a.m.	Oct. 2	6	30 a.m.	Oct. 10	1	50 a.m.	15	18	50
Oct. 22	10	20 a.m.	Oct. 30	5	0 p.m.	Nov. 6	11	0 a.m.	Nov. 15	11	0 a.m.	17	6	40
Average Duration of Complete Voyage with Hirsch's Propeller												17	5	1
Average Duration of Complete Voyage with Ordinary Propeller												18	9	18
Gain by the Hirsch Propeller per Complete Voyage												1	4	17

Equal to a gain of 11 days, 18 hours, 50 minutes, for the 12 months.

TABLE XVI.

THE HIRSCH PATENT SCREW-PROPELLER.—EXTRACTS FROM A FEW LETTERS AND REPORTS.

VIBRATION.

Admiralty Official Report of H.M.S. "Active" (600 *nominal horse-power*).—"Water butts with their "heads out have been filled to the brim and placed near the wheel; the water has slopped out to a depth "of 7 inches by Griffiths's Propeller: with Hirsch's Propeller the water was not disturbed."

Admiralty Report of H.M. Troopships "Crocodile" and "Malabar" (700 *nominal horse-power*).—"The application of the four-bladed Hirsch Propeller to the *Crocodile* and *Malabar* instead of the two-"bladed Griffiths has been followed by greatly-reduced vibration."

The Superintendent Engineer as to S.S. "Elemore" (90 *nominal horse-power*).—"The vibration has "also been reduced to a minimum and all complaints on that score have ceased."

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Captain of S.S. "*Pereire*" (1,000 *nominal horse-power*) *to Manager of Company.*—"As I had the "honour to state in my former Report, this propeller (Hirsch) has the advantage of completely removing "the vibration of the stern."

Official Letter from Owners of S.S. "*Goethe*" (600 *nominal horse-power*).—"There is a perfect "absence of vibration."

Official Letter from same Company as to S.S. "*Lessing*" (600 *nominal horse-power*).—"The first screw "caused great vibration, but when your propeller was on not the slightest vibration was perceptible."

STEERING.

Captain of S.S. "*Louisiane*" (500 *nominal horse-power*), *to Manager of Company.*—"The column of "water sent backwards by the Hirsch propeller exerts a most powerful action on the rudder, and the "vessel steers perfectly."

Captain of S.S. "*Pereire*" (1,000 *nominal horse-power*), *to Manager of Company.*—"As I had the "honour to state in my former Report, this propeller (Hirsch) has the advantage of making the vessel "steer better, and rendering it quicker in evolution of letting it be steered after stopping the engines, "which is not the case with other screws."

Report of Engineer of U.S. Fleet, of Flagship "*Worcester*" (600 *nominal horse-power*).—"The ship "steers when under sail alone with less weather-helm with the Hirsch than she did with the old screw, "having only one to one and a half turns of the wheel weather-helm when with the old screw it was two "to three turns and sometimes be hard over, and even then the ship would come up into the wind, unless "the mizen royal and top-gallant sails were taken in."

GOING ASTERN.

Official Letter from Owners of S.S. "*Goethe*" (600 *nominal horse-power*).—"The vessel goes as "quickly astern as she did before, which had formerly been doubted."

Chief Engineer's Report as to H.M.S. "*Crocodile*" (700 *nominal horse-power*).—"In going astern it "(Hirsch's screw) is quite equal to the old screw."

Owner of S.S. "*Easby*" (120 *nominal horse-power*) *says*:—"There is no difficulty in going astern."

Mr. C. E. Freund, Superintendent Engineer, as to S.S. "*Ibis*" (120 *nominal horse-power*).—"The ship "went very well astern."

Report of Engineer of U.S. Fleet, of Flagship "*Worcester*" (600 *nominal horse-power*).—"Backing upon "coming to anchor at Fortress Munroe has again given satisfaction."

Captain of S.S. "*Louisiane*" (500 *nominal horse-power*), *to Manager of Company.*—"And the "movement astern being effected with the greatest ease leaves nothing to be desired."

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Mr. H. C. Ashlin, Superintendent Engineer, as to S.S. "Federico" (240 *nominal horse-power*).—"We "had a first-rate opportunity of trying it astern as we had to take her across the river Mersey from dock "to dock under her own steam, and to leave the dock here we have to go out stern first; and on both "occasions when crossing the river and leaving again for Havana she gave entire satisfaction."

WORKING OF ENGINES.

Captain of S.S. "Louisiane" (500 *nominal horse-power*), *to Manager of Company.*—"The movement "of the engines has gained enormously in regularity."

Report of S.S. "New Pelton" (80 *nominal horse-power*).—"Working of engines improved."

Report of W. Welsh Thornton, Esq., on his S.Y. "Avalanche" (60 *nominal horse-power*).—"This "absence of vibration and smooth effect upon the working of the engines are in our opinion invaluable."

Report of Captain as to S.S. "Memphis" (150 *nominal horse-power*).—"The effect of this absence of "vibration can best be seen by the small repairs of our engines which after three years' running are as "good as new."

TABLE XVII.—"ATRATO'S" SHAFT.

Actual diameter of broken shaft	12 in.
Proper diameter as computed by Surveyors:—	
By Rankine's Rule	13·7 „
„ Anderson's Rule	13·4 „
„ Molesworth's Rule	13·9 „
„ Laird & Co.'s Rule	13·4 „
„ Mr. J. Rose, Hull Surveyor	14·0 „
„ Mr. W. Wheatley, Cork	14·4 „
„ Spencer's, used by Mr. Bipet, Liverpool Surveyor	13·2 „
„ Mr. G. Carlisle, Leith Surveyor	13·4 „
„ Mr. R. Taplin, Liverpool Surveyor	13·2 „
„ Mr. Snowden, London Surveyor	13·9 „

Particulars of the engines (compound):—Diameter of high-pressure cylinder, 57 inches; diameter of low-pressure cylinder, 90 inches; stroke 4 feet; pressure of steam in boilers, 60 lbs.; cut-off at about two-thirds stroke in small cylinder.

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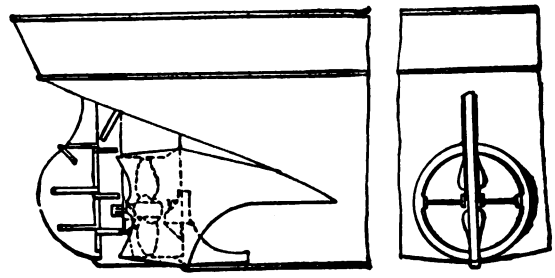
ON THE PROPULSION OF BODIES THROUGH WATER.*

By Robert Griffiths, Esq.

[Read at the Seventeenth Session of the Institution of Naval Architects, 7th April, 1876; Vice-Admiral Sir F. W. E. Nicolson, Bart., C.B., Vice-President, in the Chair.]

In bringing before the Institution this Paper on the propulsion of bodies through water, I do not intend to enter into the question of what is termed the loss by the slip of the screw-propeller or the configuration of the screw, in neither of which do I expect any naval architect or engineer at the present time to believe; and much valuable time has been wasted in reading Papers on, and discussing such erroneous ideas at Scientific Institutions.

FIG 1.



My object at present is to explain what I have already partially proved, that bodies of different forms can be propelled through the water at high speeds, in proportion to the power that is exerted to propel them, whether those bodies be of a ship-shape or any other form, such as oval, round or square. Prior to the introduction of the screw-propeller, the proportions of our sailing frigates were such as the talent of scientific and experienced men of former ages had proved to be the best for safety, steadiness, and seaworthy qualities; and I believe they will yet be found the best proportions for screw ships generally. When the screw-propeller was introduced for propelling ships naval architects and engineers found, by experience, that to obtain speed in proportion to the power exerted to drive the screw-

FIG 2.

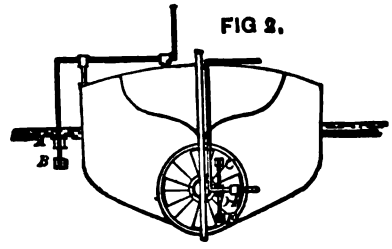
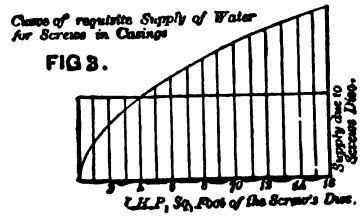


FIG 3.



* Received 17th March, 1876.

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propeller, the ship required to be constructed with very fine lines, narrow, deep, and of great length in proportion to the beam, which instead of improving the stability and safety of the ships, made them weak, crank and dangerous; but I find that equal speeds can be obtained from a ship which is three to four times her beam in length, and the draught of water one-quarter to one-third times the beam.

The model, Fig. 4, by which I think I have proved that this can be accomplished, is 3 feet 3 inches long, 1 foot 2 inches wide, $3\frac{1}{2}$ draught of water, and was tried against another model (Fig. 5) 5 feet long, $7\frac{1}{2}$ inches wide, $3\frac{1}{2}$ draught of water, the weight and displacement of each being the same, and they were propelled by the same spring and screws. The resistance of the models when drawn through the water, instead of being propelled by the screws, was as five is to three, and yet the speed was rather in favour of the short model though it offered the greatest resistance. This is overcome in the short model by the screw obtaining its supply of water from underneath at a distance forward, before it begins to flow into the space left by the ship, and also by the way the water is delivered from the propeller; while the long model, which is fitted with the screws in open water in the ordinary manner, is subject to two unavoidable defects, the first being that the screws draw their supply of water from the ship's quarters, which deprives her of the water that is required there to fill the space left by the vessel; and secondly, the screw drives a column of water backward, which meets and retards the water which would then flow forward after the ship if propelled by sails, and causes a serious resistance to the speed of the vessel. I believe it will be generally admitted that there is a considerably greater resistance to the ship when the screw is in operation, which is attributed solely to the screw drawing the water from the stern of the vessel; but I find the resistance is divided between the suction and the delivery of the water by the screw. By the present system of placing the screw at the stern of the ship, the loss occasioned from the suction of the screw can be modified by fining the lines at the stern to allow a better supply of water to the screw, or by removing the screw further back; but I can see no remedy that can be made for the water that is forced back from the screw as long as it is worked in open water in the ordinary way. When however the screw is worked in a casing, if the discharge

FIG 4.

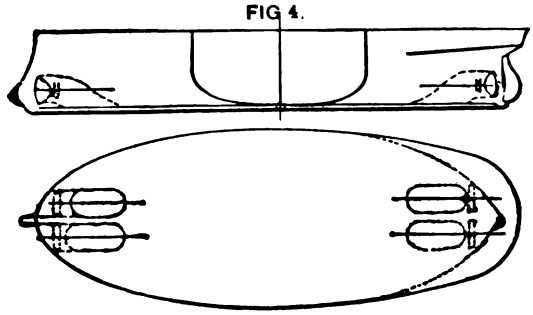
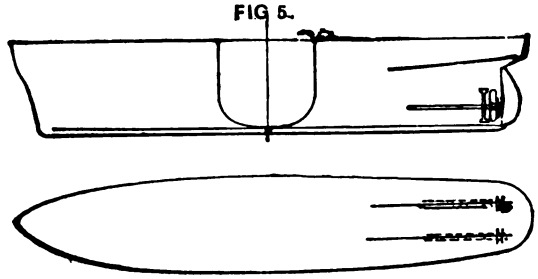


FIG 5.



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ends of the tunnels are formed at an angle of about 45° horizontally with the line of screw shaft towards the rudder, 40 per cent. more area will be allowed; so that the water that is forced from the screw meets the still water at the stern and mixes with it, while the remainder fills up the space left by the area of the screw tunnel, leaving the water at the stern of a screw ship in nearly the same condition as it would have been at the stern of a sailing vessel.

I will now explain how any other than the ship form can be propelled at moderate speeds through the water. I will first take an elongated body of say 30 feet wide and 7 feet deep and 50 feet long, or upwards, according to the amount of displacement required, with either square or round ends, drawing 6 feet 6 inches of water; the immersed ends would be 195 feet area, and if fitted with four screws of 6 feet 3 inches diameter, in tunnels at each end, they would take about 200 feet of water through them, or just in proportion to the amount of power applied to drive the screws. The tunnels for the screws to work in would require funnel-mouths of such capacity as to admit the quantity of water the screws required.

According to Colonel Beaufoy's experiments there does not appear to be much difference in the resistance of bodies propelled through the water, whether their ends are made in a wedge form vertically or horizontally, provided the angle of incidence of that wedge is made to give the least resistance at the speed it is driven through the water. There can be no doubt since the screw-propeller can be made subservient in its operation to propel bodies of any form (instead of being antagonistic, as when it is now applied for propelling ships), first by removing the water at the forward end or bow, and placing it at the stern or after end where it is required, a speed commensurate to the power employed to propel it will be obtained, provided the wedge form at the bow and stern of the body that is to be propelled be made at such an angle as would give the best result according to the power that is exerted to propel it. It may appear objectionable on account of the reduction in the displacement to elongate the angle of incidence at the bow and stern, which would be of no material consequence, since a very slight lengthening in the midship of the body to be propelled will make up for it.

With regard to what form of ship offers the least resistance in being propelled through the water, I am not aware of any reliable information where the body that was to be propelled acted in harmony with the instrument that propelled it, except in sailing vessels, in which experience has proved how the propelling power, the wind and sails, and the ship's form, can be made to harmonise with each other to obtain the best result. Since the introduction of the screw-propeller, the object which chiefly

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occupied the attention of engineers and naval architects was to obtain the greatest speed which the power exerted by the engine could give, and very little attention was paid to anything else except what they termed the loss of speed by the slip of the screw—a greater fallacy than which could not have been conceived.

There can be no doubt that, unless the supply as well as the discharge of water necessitated by the screw can be carried on without being detrimental to the speed of the ship, partly by drawing the water from the stern and discharging it from the screw in such a way that it does not draw the water from the stern or keep back the water that is flowing forward after the ship, a great amount of the power that is given out by the engine is consumed to overcome these obstructions. We will suppose for a moment if there was a screw-propeller in operation worked with power equal to propel the ship at 10 knots, though not in any way connected with the vessel, but worked at the stern of a sailing ship going at 10 knots, the resistance to the sailing ship in that case would be very considerable. I believe Mr. Froude has made the experiment, and found the resistance to the ship, when the screw was at work, was just double what it was without the screw; this loss that is occasioned by the action of the screw is much reduced on my system, as the screw neither draws the water from the stern of the ship nor stops the forward flow of the water that follows it.

Fig. 1 represents the stern of H.M.S. *Bruiser*, fitted with a casing over the screw, having a funnel-mouth to it of 1 foot greater diameter than that of the screw, and a small lip below that admitted altogether about 40 per cent. more water than that due to the screw's disc. The speed of the *Bruiser*, before the casing was applied, was 8·016 knots, and with the casing 8·280 knots, all other circumstances being the same. I have no doubt that if there had been a different screw, and the mouth of the tunnel supplying it had been placed forward so as not to take the water from the stern—such as I have found to give the best result in models—a much better result in speed would have been obtained. The casing stopped the vibration from the screw, and prevented the racing of the engines in a heavy sea. The screw-propeller, when worked in a casing, is a rotary pump, and subject to the same laws—*viz.*, doubling the speed of the water forced through it—requires four times the power which will give a corresponding thrust to the screw shaft; and in order to prove several points which do not appear to be well understood in screw propulsion, I tried a number of experiments on a small launch at Keyham. Fig. 2 represents it with the apparatus to indicate the pressure of water as it left the screw. Under different circumstances the pressure varied considerably at different places of the screw's disc as shown; but when the screw was disconnected, and the launch towed at a speed of 6 knots, the screw revolving at the rate of 4·2 knots, the mean pressure over the screw's disc was 0·76 pounds per square inch; when the screw was working, and

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the launch moored, it was about 0·55 pounds with 240 revolutions of the screw; and when the launch was propelled by her screw at 6 knots, the mean pressure was 1·65 pounds per square inch, and 250 revolutions per minute, and 0·85 pounds outside the launch (as shown on diagram). I may here mention that in neither the *Bruiser* nor the launch was the supply of water drawn in as far forward as to avoid the suction from the stern of the ship, which is one of the greatest advantages to be derived by my system. There is no gain in speed to be obtained by the application of the casing when the power is less than 4 indicated horse-power to each square foot of the screw's disc; for in the launch where the indicated horse-power was $3\frac{1}{2}$ to each square foot of the screw's disc there was a loss of about $\frac{1}{4}$ of a knot, and no doubt the loss in speed would have increased as the horse-power was reduced in proportion to the area of the screw's disc; for the screw when worked in a fine run in a small vessel obtains all the water it requires for that proportion of power without drawing it away from the stern so as to retard the speed of the ship.

Fig. 3 is a curve showing the quantity of water the screw requires, according to the power that is applied to work it. This curve does not extend beyond 16 indicated horse-power to each square foot of the screw's disc, though I have no doubt it might be extended much further with safety, since the *Waterwitch* could be propelled nearly as effectively by a screw with about 75 indicated horse-power to each square foot of the area of the discharge pipes.

DISCUSSION ON THE TWO PRECEDING PAPERS.

Mr. J. Fortescue Flannery: There is one question which, with great respect for Mr. Griffiths's able Paper and what he has said with regard to screw-propellers, I would wish to ask him. I find in the opening of the Paper he makes this remark: "I do not intend to enter into the question of what is termed "the loss by the slip of the screw-propeller or the configuration of the screw, in neither of which do I "expect any naval architect or engineer at the present time to believe. Much valuable time has been "wasted in reading Papers on and discussing such erroneous ideas." The interpretation which this paragraph bears is that Mr. Griffiths believes that, no matter what may be the form of the screw, the result in the economy of propulsion and consumption of coal will be entirely the same. I am really much surprised that a gentleman, who was the very first to call attention to the difficulties of the ordinary system of screws, should be the very first to go back upon his own labours and condemn them in such a wholesale manner. It may be, however, that I have misunderstood the remark. Mr. Griffiths will perhaps explain that in his reply. This brings me to notice that Mr. Pendred's Paper includes a large number of differently-formed screws, and on looking over the diagrams there is one which I must confess seems to bear within it the promise of a much more economical performance than some of the others.

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I allude to the screw with the curved blade. Perhaps I can explain my reason better by reference to the black board. Suppose *this* [*illustrating*] to be the centre of the shaft, and we have a straight blade as the common screw usually is formed, then as the screw goes round there is a large amount of centrifugal action set up and a large amount of power lost by that centrifugal force falling away from the centre. If, however, we curve the blade in *this* direction, as is shown upon the diagram, the other blade being curved so, then we confine the centrifugal force much more towards the centre, and it is converted into a forward motion. Then again, what is the cause of vibration in screw-propellers? I believe that, *this* being the stern-post of the ship, as the screw goes round, if the blade be straight, there is a lateral blow struck upon the stern-post at the top, a corresponding lateral blow struck at the bottom, and that results in the vibration of the whole ship; whereas, if you curve the blade in *this* direction, so that by following this dotted line the tip of the blade will pass through the aperture before the next portion, and so on, then the blades will pass through gradually, giving a gradual lateral blow to the stern-post, and you do not have the same chance of vibration as you have with the straight blade. Then there is just one other point. The author says he does not know the reason why the *Britannic* was condemned and why she is now being altered—or rather why she has been altered, because her alterations are complete—at Belfast. I happen to be in a position to inform him of the reason. The bottom part of the propeller being below the keel line and the upper part of the propeller being above the keel line, as the screw went round the upper blade gave a lateral blow to the stern-post in the same way as I have described; but there was no counteracting blow on the under side of the shaft, and the result was vibration to an enormous extent; and this was further increased by the propeller being so much lower down, and having so much more leverage. The arrangements for water-tight work were shaken completely to pieces, and great expense was necessarily incurred at the end of each voyage to make them tight. Then there is another point in Mr. Pendred's Paper which, I think, it is only justice to Mr. Wimshurst I should take notice of. That refers to the scheme for raising the screw out of the water. The scheme I allude to was for raising the screw-propeller out of the water in sailing ships when the vessel was under sail alone. This was effected by a universal ball and socket joint in the shaft. I am informed, and know quite well it is the case, that this invention was anticipated and patented by Mr. Henry Wimshurst in 1863, and it has been most valuable in some cases. I think it is only just that the right inventor should have the credit of his ingenuity.

Mr. J. Mac Farlane Gray: I was about to say what this gentleman has already said as to the gentleman by whom this invention was patented. I think Mr. Henry Wimshurst is here. He is undoubtedly the inventor of the lowering shaft if there is anything in it.

Mr. Henry Wimshurst: I may perhaps be allowed to say a word or two upon this subject. I have heard a great deal said about screws. I built the first two ships in which screws of this kind were applied; and since then I have carried out a series of experiments at my own cost. The first was in the *Archimedes*. That was not done at my own cost, but at the cost of the Ship's Propeller Company. The second was at my own cost for two years. But there is one great drawback to the screw-propeller which has not been named at present, and that is, as you all know, that the water passing under the ship's stern goes at the same rate on both sides. The screw when the arm is coming up with the current of water is coming with the current at the same rate. Say the screw is 15 and the vessel is going 15—that goes up as it were smooth, but the moment it turns it meets the water on the opposite side of the post at 15 coming up and 15 going down, giving an enormous blow. Now my object in the arrangement in the *Archimedes* was to give plenty of room for the screw at either end. It only wants room—nothing before

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and nothing behind, and then there is no shock; but the moment you contract the openings you must have the shaking of the stern. I would recommend in all cases where it can be done—I had to do it with the *Archimedes* screw fitted in quite close—that it should be cut in half. Then we got over the shaking of the stern, but not altogether. Then with regard to the novelty of it we all know that things have gone on progressing since the time I refer to. I put the first engine to drive the vessel on the screw principle, and all I would say at the present time is that anybody can make a screw and anybody can talk about a screw, but I had the honour of building the first two successful screw steam ships.

Mr. H. W. PENDRED: I do not know that I need take up your time by making any remarks. One gentleman has made an observation that he believed the curved-bladed screw was better than a straight-bladed screw. I am disposed to agree with him on the principle of the water being scooped in at the centre; but at the same time I would observe that as to the exact curve which would give the best results there is no rule as far as I know by which it can be established. With regard to the question about the *Britannic*, I have to thank the gentleman who spoke on this subject very much for the information. I felt a good deal of interest in that lowering gear, and was very much at a loss to understand why that was removed. With regard to the observations of Mr. Wimshurst I am quite disposed to agree with him also; and I think that the less water there is above the propeller the better. I think it only remains for me to thank the Members for the courtesy and attention which they have given me.

Mr. R. GRIFFITHS: I would make one observation upon the remarks which have been made by Mr. Pendred in his Paper as to the *Bruiser*. She was sent away from Plymouth to the Scilly Islands to try her effect. When she came back I asked Mr. Watson, the chief engineer, what he thought of her. He said, "I will tell you candidly what I think. I hope they will not put me in a ship again without "casing over the screw; we were out in nasty weather, she never raced at all, and there was no vibration "whatever." With regard to the screw question I may remark that upwards of 20 years ago I made a good many experiments at Portsmouth on the *Fury*. At last we took a blade that was perfectly flat and had no twist in it; and it came, within a very trifling difference, to the same as that which Mr. Wright said. There was not near half a knot extra speed. When I first went with my screw to Mr. Lloyd the first thing he asked me was, "What speed do you expect to get?" I said, "I do not expect to get much; "but if you get the right pitch on the screw, you may manage to get half a knot." The remark he made was, "I believe you, because every one that comes here with a new screw never gives us less than 4 or 5 "knots extra speed." My conviction after all my experiments is, that if you take four strips of plate iron and set them up at an angle that will hold the engines at the speed you require, it will give you within half a knot of the best screw that was ever brought out.

The CHAIRMAN: I am sure you will all thank the two authors for the Papers which they have just read; and I cannot help saying that Mr. Griffiths' allusion to what the inventors of screws always say they will gain in speed reminds one of the old formula with regard to every new invention relating to steam engines, which was always a case of a saving of 75 per cent. of fuel.

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ON WATER-TUBE BOILERS.*

By J. Fortescue Flannery, Esq., Member.

[Read at the Seventeenth Session of the Institution of Naval Architects, 7th April, 1876; Vice-Admiral Sir F. W. E. Nicolson, Bart., C.B., Vice-President, in the Chair.]

Much public and professional attention has lately been drawn to the official enquiry held at Liverpool by the Board of Trade into the loss of life caused by the explosion of portions of the water-tube boilers of the steam ship *Propontis*. This is rightly regarded as a most important case; and as other attempts to improve the construction of marine boilers, although very fully discussed in the Press, have never been directly brought under the notice of this Institution, I venture to offer a short *résumé* of some of the principles and facts involved in the question.

The almost universal adoption of high-pressure steam at sea has brought with it much inconvenience, notwithstanding its great economy of fuel. The anxiety attending upon the construction and the working of the marine boiler is much greater now than formerly; its first cost is largely increased, the expense of repair is much more, and the duration of its life is much less. I think I shall have the concurrence of the Members in saying that one of the gravest, if not the very gravest and most important, of the questions now arising in connection with the machinery of steam ships is the improvement of the marine boiler. And not only does the present practice leave much to be desired, but the feeling in favour of still higher pressure is checked chiefly by the difficulty of designing a boiler which will sustain it safely and efficiently. It is an axiom laid down by theory, and confirmed by practice, that the higher the boiler pressure and the greater the ratio of expansion the greater is the economy of fuel. Theoretically, this axiom is sustained by the fact that to generate steam of the pressure of 30 pounds per square inch about 1,190 degrees of heat are required, while to generate steam of 120 pounds per square inch about 1,218 degrees of heat are required, that is to say, to produce steam of four times the boiler pressure less than $1\frac{24}{1000}$ times the heat is required. Again, a boiler pressure of 240 pounds per square inch requires about 1,235 degrees of

* Received 16th March, 1876.

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heat, or $1\frac{4}{100}$ times the heat of steam at 30 pounds, and contains eight times the initial force. Practically these differences are so small that the same consumption of coal may be taken to evaporate the same quantity of water, whatever the pressure. Theoretically, therefore, we have only to increase our boiler pressure to reduce our consumption of fuel, were it not that two well-ascertained considerations intervene. First, we have not hitherto been practically able to construct a boiler which, under usual conditions of steam-ship requirements, will stand a pressure greater than is now in use; and second, the heat of very highly-pressed steam burns up the lubricant in the engine cylinder, quickly destroying the working parts. With the second consideration, however, we have not now to deal; and if we could overcome the difficulty of making a boiler to bear even 120 pounds with safety, much improvement would be effected.

To start from the beginning, let us remember that the thickness of the shell of a cylindrical vessel containing high-pressed steam must, in order to maintain the necessary strength, be increased directly in proportion to increase of pressure and diameter, and that the thickness of the shell may, consistently with the strength necessary for any given pressure, be reduced, if its diameter be also reduced. A very usual size for modern high-pressure cylindrical boilers is say 12 feet diameter; and the thickness of the shell of a boiler of this diameter, double riveted to bear a pressure of 120 pounds per square inch, would be fully $1\frac{1}{2}$ inches. I am not aware of any examples of boiler construction where the thickness of the shell plates has exceeded $1\frac{1}{4}$ or $1\frac{3}{8}$ inches; and it is almost doubtful if, considering the practical difficulties of manufacture, a perfectly good job is made with shell plates of this thickness; at all events, it is generally accepted that to make sound workmanship with a thickness greater than this is practically impossible. On the other hand a cylindrical vessel or tube say 12 inches diameter may, for this same pressure of 120 pounds per square inch, be made if welded only $\frac{3}{16}$ inch thick, and still possess the same proportionate strength; or, for a pressure of 150 pounds per square inch, it would be made practically about $\frac{5}{16}$ inch thick, and this would give a factor of safety nearly three-fourth times greater than that possessed by the cylindrical boiler shell 12 feet diameter $1\frac{1}{2}$ inches thick and pressure of 120 pounds. It is practically certain, therefore, that the limit of pressure with the present type of boiler has been reached; and when we consider how much economy of fuel has been effected by increasing the pressure to its present height, and how much more economy may be effected by still further increasing the pressure, it will be seen that the adaptation of an efficient high-pressure marine boiler would meet a great and increasing want.

Many look for the solution of this problem to the type known as the water-tube or tubulous boiler—that is, the system by which the cylindrical portions of the boiler subject to internal pressure are reduced in diameter and increased in number, the result

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being that for a given weight of material a much higher pressure of steam is carried; and, indeed, by the reduction of the necessary thickness of the shells a higher pressure of steam is carried, and more economy of coal insured than is possible with any other type of boiler. The other advantages claimed for boilers of this type are:—that the thinness of the metal interposed between the fire and the water enables the heat to be conveyed more efficiently and with less waste, and also enables the steam to be raised more rapidly; that the danger of explosion is limited; that a damaged tube can be easily replaced; that greater strength proportionate to the pressure being possible in first manufacture, the wear of the metal in the boilers need not at a later date enforce reduced pressure, and therefore reduced speed of ship, as is the case with existing types of boilers. It is pointed out also that where boilers of the ordinary type require renewal the decks must be broken away, whereas the separate portions of the tubulous boiler may be passed down the hatchway; and further, that a war ship in a foreign station must either return home or to the nearest dockyard, in the event of any serious wear upon ordinary boilers; but so many spare tubes of the water-tube system might be carried as to greatly extend the period of service upon a foreign station.

There is a diagram of a boiler of the ordinary type, showing the advantage possessed by the boiler of the water-tube arrangement, as regards having the current of the flame and heated gases running in a direction at right angles to the surface of the plates in contact with the water.* It is noticed that the direction of the flame in the ordinary boiler is always along the faces of the heating surfaces, whereas in the water-tube boiler it is in a direction at right angles to them; the heating efficiency of flame striking the plate directly, as in this latter case, must be much greater than when sliding along the surface; and we see, therefore, that this system not only enables thinner plates conveying the heat more perfectly to the water to be used, but also directly increases the action of the flame itself. Again, the escape of the steam bubbles from the metal surface upon which they are generated is more rapid and direct when that surface is disposed horizontally. The condition most essential to safety is, beyond doubt, good circulation. The heat to which a tube immediately over a fire is exposed amounts to upwards of 2,000°; the specific heat of water or its power to absorb heat is twice that of steam, and in addition the evaporating water absorbs the latent heat of steam, making its receptive power many times that of steam; there is, therefore, no difficulty in arriving at the conclusion that a tube of say $\frac{3}{8}$-inch thickness, which is not relieved by freely-circulated water, will become hot and dangerous in a very few seconds, and it may be shown that the absence of provision for this good circulation has been the primary cause of the difficulties the water-tube boiler has yet encountered.

* This diagram of a boiler of the ordinary type it has not been thought necessary to reproduce here, as it is so well known.—Ed.

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It may be noticed, on reference to the diagrams, how large a body of water is contained by the ordinary boiler, as compared with the volume of water held by the water-tube boiler in proportion to their heating and grate surfaces. The effect of this is that the ordinary boiler has a large reserve of water at nearly boiling point, and is not, therefore, exposed to such sudden fluctuations of pressure, with their attendant evils, as the water-tube boiler. If the strength of the fires be suddenly increased in a water-tube boiler, a spasmodic rise of pressure, leading to accumulation of steam in the water chambers, priming, loss of water, and overheated tubes takes place, and this defect is quite absent from the ordinary boilers; and not only so, but the large reserve of water in the ordinary boiler, the whole of which above the fire-bar level must be heated to nearly boiling point, is the cause of a much more gradual, and therefore more easily-effected circulation of the water; indeed, the small volume of water is still further reduced by the isolated sub-division of the parts—each tube having to supply, circulate and evaporate in a very independent manner, and with little reference to the volume of water contained by its neighbours. Clearly the smallness of the contents of a tubulous boiler is in some respects a serious drawback, although it is in other respects an advantage. The difficulty of obtaining a good circulation is from the nature of the case greater in the tubulous boiler, and the increased friction of the water due to high pressure adds to this difficulty, while at the same time it increases the necessity; and it is a matter for the earnest consideration of inventors whether artificial circulation, produced by sub-divided feed inlets or otherwise, may not after all be resorted to. This idea has been expressed to me by one of our most eminent marine engineers, and it does seem that the certainty of good circulation thus obtained would compensate for the complication of working parts.

One element of danger absolutely possessed by the water-tube boiler, and not shared by the ordinary boiler, lies in the fact that the metal exposed to the direct action of the fire is at the same time subjected to the tensile strain of internal pressure. In the ordinary boiler the parts subjected to tensile strain are not acted upon by the fire, and those parts acted upon by the fire have the water surrounding them with a compressing strain. Although the crushing strain of wrought iron is less than its tensile strain, the case in point of the fire playing upon iron under tension is more dangerous, because any flaws will be stretched out, the flame will penetrate them and promote their increase to bursting point.

The water-tube boiler has, under several designs differing in their details, been extensively used for the generation of steam in factories, and for other stationary purposes both in England and America; and although some important defects exist and some unfortunate failures have occurred, still it cannot be denied that, as a rule, its

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results have been fairly satisfactory. Why, then, has it not come into more extensive use at sea? It may be answered generally that the conditions to be fulfilled on board ship are more stringent, the space allotted is more circumscribed, and the boiler must conform to its limits. A less leisurely and methodical action is necessary than in a machine used for stationary purposes, and defects of little importance on land develope into serious evils at sea. We may best elucidate this question, however, by considering some of the cases in which the water-tube boiler has been tested for marine purposes, and by analysing the causes of failure in these cases. Several practical trials at sea have been made, and the enterprising and truly admirable spirit displayed by two steamship owners especially cannot be too highly commended. The gentlemen alluded to are Mr. S. B. Guion, of Liverpool, the managing owner of the steamship *Montana*, and Mr. W. H. Dixon, of Liverpool, the owner of the steamship *Propontis*. The examples in these vessels being the most recent and by far the most important trials of the water-tube system I propose to draw your attention to them first.

The *Montana* is a steamship of more than 4,000 tons, and was built for service on the Guion line between Liverpool and New York. Amongst other innovations, she was fitted by Messrs. Palmer, of Jarrow-on-Tyne, with boilers intended to work at 100 pounds pressure, and it was anticipated that the economy of fuel would be very great. Figs. 1, 2 and 3, will convey a good idea of the nature of the design. Each boiler was composed of tubes 15 inches in diameter and 15 feet long, sealed at the ends,

FIG. 1.

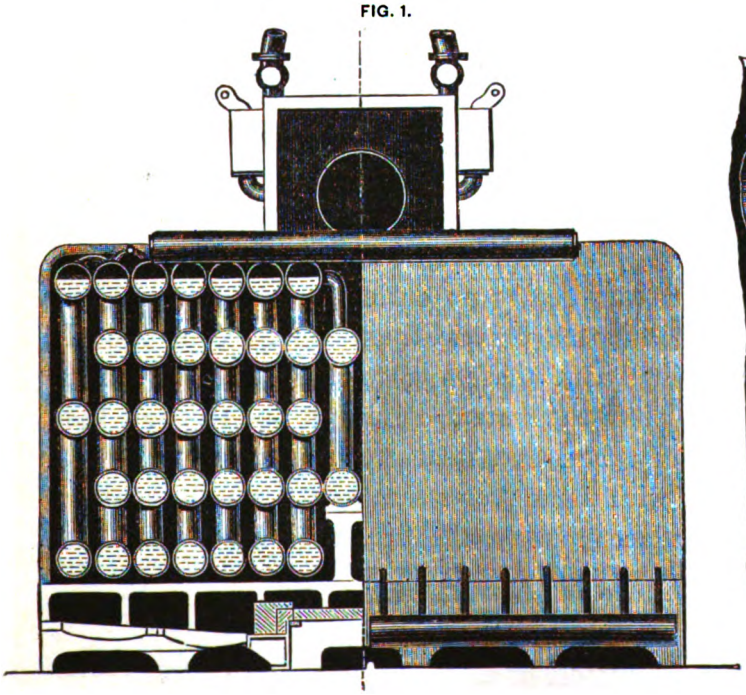
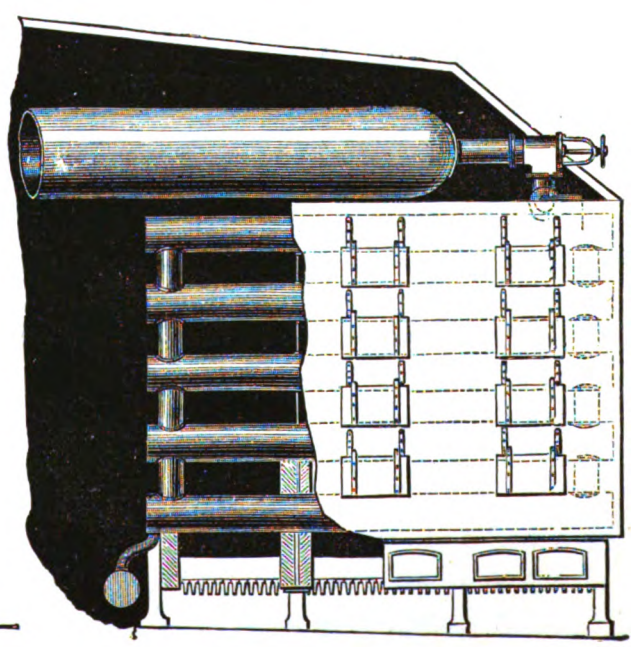


FIG. 2.



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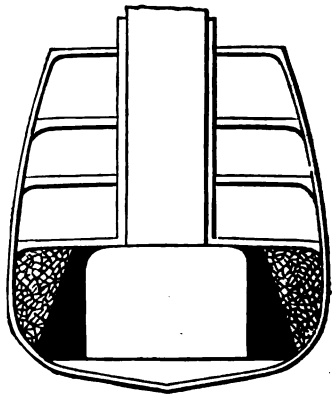
but communicating with each other by vertical necks about 6½ inches diameter; there were five horizontal, or nearly horizontal, rows of these tubes in each boiler, and each row contained seven tubes. Noticing the profile, it will be seen that to carry off the steam generated, and to promote circulation of the water, each horizontal tube was supplied with two necks. As the steam must all rise to the top, the necks between the bottom tube and the one immediately above must take up the steam generated in the bottom tube,—the neck between the second row from the bottom and the one immediately above it must take not only the steam generated in the second, but also that in the first row, and so on,—the neck nearest the top having to convey the steam generated in the whole of the tiers of tubes below it. In addition to these tubes there are in the uptake three steam reservoirs or superheaters 3 feet diameter. In designing the boiler the two vertical rows of tubes nearest the fire-door were set apart for the purpose of heating the feed water, and the six other vertical rows of tubes farthest from the fire-door were set apart to generate steam from the feed-water so heated. In accordance with the duty thus assigned to them, the two rows of tubes vertically nearest the fire-door had the feed pipes connected to them at the top, and had small pipes only ⅞ inch diameter fitted also at the top to carry away any steam which might happen to be generated. It was, of course, expected that the current of the feed-water passing through these two feed-heating sections would be so rapid, and that the fire under them would be so much less vivid nearest to the dead plate, that the water could not whilst in them absorb sufficient heat to evaporate. The water was delivered from these feed-heating sections into a large feed-water chamber, which supplied the other sections. The two sections designated as feed-heaters are so called, though as a matter of fact they were not feed-heaters only, but calculated to generate steam nearly as much as any of the other tubes in the boiler, and the steam had really no outlet, because the ⅞-inch pipe provided for the purpose was so small as to be practically useless. The natural action of the steam generated in these sections was, therefore, to rise to the top tubes, to accumulate there, and to depress the level of the water, driving it out through the bottom pipes from all that vertical section of tubes, and finally exposing to the direct action of the fire a bottom tube filled only with steam, or steam and a small quantity of water. This is exactly what did take place, and on the first trial passage of the vessel from the Tyne towards the Mersey five of the tubes burst. These tubes were all situated in corresponding places in the different boilers—that is, the lowest tube in the inner feed-heating section. After this experience the connections were altered, so as to

FIG. 3.



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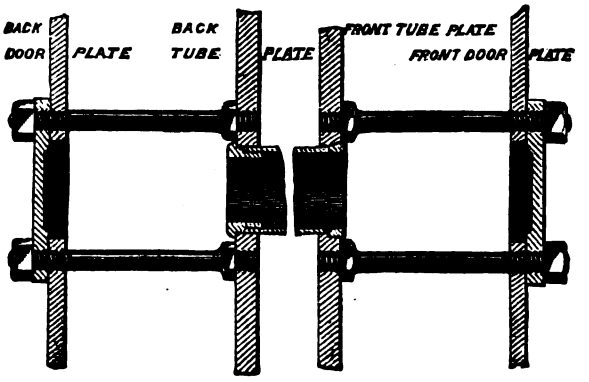
join this inner feed section to the rest of the steam-generating part of the boiler, leaving the outer vertical row only to act as feed heater. For some few hours this arrangement gave promise of better success, but after a day and a half's working, two more tubes, one of them the fourth from the front in the bottom row, gave way; and the owners, completely discouraged by these failures, and taking into consideration also the fact that the boilers were heavier and more bulky than boilers of the same power of the ordinary kind, decided to condemn them and replace them by ordinary cylindrical boilers. The cause of the failure of the sections devoted to feed-water heating appears sufficiently obvious, and as the separation of these sections was a special feature in this example, and is not likely to be repeated in other water-tube boilers, we may dismiss it from further consideration. But the bursting of the other tubes is more serious, and appears to more closely affect the general principle of water-tube boilers.

A very able article, from which some of the particulars given above have been drawn, appeared in the *Nautical Magazine* on the subject of the *Montana's* boilers, and it is there suggested that the cause of the explosion of the inner tube on the bottom row was the absence of a sufficiently large steam connection between the top or steam-holding chambers to counteract the inequality of pressure in them. It will be noted that the feed-pipes for all the sections are common to one feed-water chamber; and, supposing any inequality of steam pressure to exist, the water would of course be forced from the chamber containing the highest pressure to those containing a lower pressure. The steam pipes connecting the upper chambers were 2 inches diameter, and the area of the fire-grate under each section was about $7\frac{3}{4}$ square feet. A very simple calculation shows that these 2-inch pipes were very small if any large difference in pressure were to be equalised. Another explanation, and one which appears quite reasonable, was advanced by Mr. John Watt; he calculates that the grate surface, 7·75 feet, acting upon the water in each bottom tube, is equal to the evaporation of 12·83 pounds of water, or 78 cubic feet of steam at 50 pounds pressure per minute. Now, the only orifices through which this quantity of steam may escape are the before-mentioned pair of $6\frac{1}{2}$-inch vertical necks, which have each an area of 33·18 square inches; one of these would probably be a downcast for the water, and the other, at the higher level, being an upcast for the steam, the steam would therefore rush through this neck at the rate of nearly 340 feet per minute—a speed so great that the



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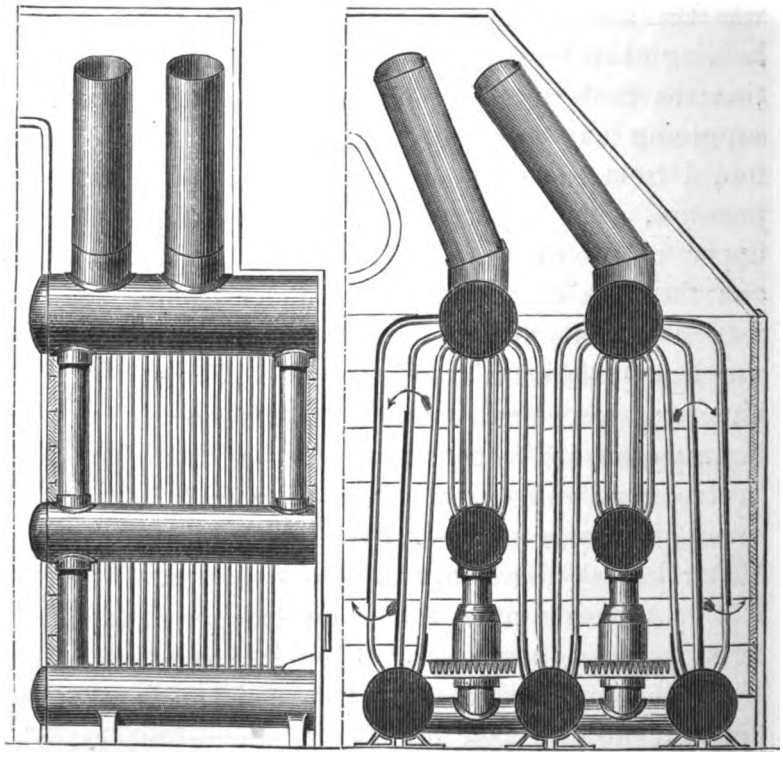
assumption that the steam would drag the water upwards from the bottom tubes, leaving them exposed to the fire, does not seem exaggerated. Whichever of these explanations be correct, it is evident, in the light of the experience now gained, that the failure of these tubes in the *Montana's* boilers proceeded from easily-preventible causes, because in a future design the feed-water arrangement could be omitted, and the steam connections to equalise the pressure in the different sections could be enlarged; the vertical necks for the escape of the steam could be much increased in area; and it is possible that if these alterations had been effected upon the *Montana*, a result very nearly approaching success would have been obtained. Indeed it was most unfortunate in the interests of science that no further experiments were made with this vessel; she was condemned after a series of trials extending altogether over not more than five or six days.

The *Propontis* is a steamer of about 2,000 tons, belonging to Mr. W. H. Dixon, of Liverpool. In 1874 she was fitted by Messrs. John Elder and Company with boilers on the water-tube principle, under Rowan and Horton's patent. From the diagram, Fig. 4, it will be seen that they are four in number, having one chimney, and each boiler consists of seven horizontal cylindrical vessels, connected together by vertical tubes 12 inches diameter, supplemented by numerous pipes $2\frac{1}{2}$ inches diameter; the space for steam in the upper vessels being increased by four diagonal domes. To further guard against priming, tubes are carried directly from the steam dome down to the lowest vessels, so that any water carried up by the steam will be broken from it in the upper chamber, and fall down again to the lowest level; the feed is also delivered at the bottom chambers. Baffle plates are fitted to circulate the flame among the tubes. It will be noticed that the lower or water chambers were connected, but no connection was made between

FIG. 4.



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the upper or steam chambers; the importance of this omission is obvious, and was discovered in the working of the boilers, as will be seen further on. The working pressure intended was 150 pounds. While the defects in the boilers of the *Montana* exhibited themselves after a few hours' work, the boilers of the *Propontis* continued their promise of success for a much longer period; and indeed were exhaustively tested at sea for a time extending over several months. The first voyage of the *Propontis* was from Liverpool to the Black Sea and back, and very careful observations of the working of the boilers were made. The consumption of coal taken during a run of ten hours was 1·54 pounds per indicated horse-power per hour; the pressure of steam being easily maintained at 130 pounds to 140 pounds. It is by no means certain that the full advantage of the *Proponti's* boilers, in point of economy, is represented by the above figures, because the baffle plates for the deflection of the flame were not arranged just in the way that experience afterwards showed they should be arranged. So far the career of the tubulous boiler in this ship was fairly satisfactory and sufficiently promising; but before long evils, which had been gradually accumulating, developed themselves in an unpleasantly conspicuous manner. It will be noticed that some of the smaller-sized vertical tubes terminate in S bends at the points where they join the horizontal vessels. The peculiarity of this bend rendered it impossible to clean the tubes from scale, so that salt water could not be used; indeed, precautions of an unusually perfect character were taken to admit pure distilled water only to the boiler; and the action of this distilled water, unmixed with any salt, was just what might have been expected: a corrosive action was set up in the tubes, some parts of the internal surface were quite untouched, while other parts close to them were perforated by circular blotches of corrosion of $\frac{1}{2}$ inch to $1\frac{1}{2}$ inches diameter. These were continually giving out, allowing the steam and water to escape upon the fires. The defects were temporarily remedied by drawing the fires and binding a ligature round the injured tube over the hole, and these little explosions were of such frequent occurrence that one of the four boilers was almost constantly disconnected.

In the early part of 1875 the boilers underwent a thorough repair, being supplied with some 300 new tubes, and were tested by water pressure to 275 pounds. After this a small quantity of sea water was allowed to enter the boilers to make up the waste, and after completing another voyage to and from the Levant, they were opened up and found to be coated with a slight scale. In September of last year the *Propontis* commenced another voyage, but on the third or fourth day the wing chamber of the forward starboard boiler burst, injuring two men, the pressure at the time being 150 pounds. The rent was nearly 2 feet long and was in the solid plate, near the lower side of the tube, and about its middle length. At Lisbon this was repaired by riveting on a patch $\frac{3}{8}$ inch thick.

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Leaving Lisbon, she had been but a very few days out before another explosion took place, the pressure at the time being only 105 pounds. The fracture was in the wing chamber of the starboard after-boiler, and was again in the solid plate, at the lower side of the chamber; the rent measured 12 inches by 7 inches. The diameters of the tubes which gave way were 21 inches, the plate $\frac{3}{8}$ inch thick, and the bursting pressure of this would be 1,200 pounds, provided the plate were cool and uninjured. Putting into Algiers, the boilers underwent an inspection by French engineers, and in accordance with their advice the furnaces were partially bricked up, and the pressure reduced to 60 pounds. It may be here remarked that the opinion of the French engineers that a reduction of pressure meant in the case of these boilers greater safety was very questionable. It may be a paradox to say that the lower the pressure the greater the danger, but in the case of water-tube boilers, under certain conditions, that is the fact. Let us remember that a cubic inch of water will make a cubic foot of steam of the same tension as the atmosphere, and that the greater the pressure the less is the bulk of any given quantity, say a pound weight of steam. Now as the power of a boiler may be measured by the number of pounds weight of steam that it evaporates, the *Propontis'* boiler would evaporate really no greater quantity of steam at 60 pounds pressure than it could evaporate at 150 pounds pressure; but whatever steam it did evaporate would at 60 pounds pressure occupy more than twice the space it would occupy if at 150 pounds pressure. Again, evaporation cannot take place without circulation, and circulation is the mutual changing places of the steam as it is generated and the water about to be evaporated; if therefore, the steam occupies twice the volume, then there will be twice the space for it to travel through, to circulate or change places with the new water; and as one dangerous defect in the *Propontis* was insufficient circulation, it is seen that by lowering the pressure the French consulting engineers may not at all have increased the safety of the boiler. It is a most interesting investigation, but one which I fear can only be conducted practically, to learn how far the increased friction varying directly as the pressure compensates for the decreased volume of the evaporating steam. The vessel was towed from Algiers to Gibraltar, and then the extra firebricks were taken out, a baffle plate between the chambers and the fires was fitted, and test cocks were placed on each water chamber. Under the protection of the baffle plates the vessel steamed home with three boilers.

Upon final examination it was found that the vertical tubes were bulged and distorted in several places, and all the horizontal tubes exposed to the direct action of the fire were more or less bulged upon the lower sides, thus affording clear evidence that in most of the water chambers of the boiler steam was sometimes collected. These bulgings or partial injuries to the boiler evidently arose from defective circulation, and

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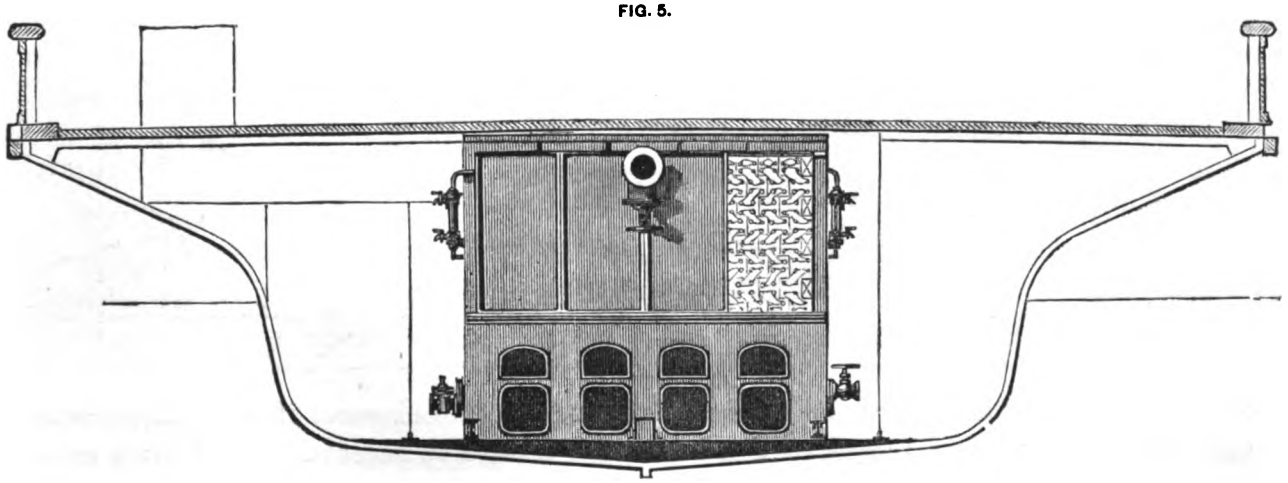
the bursting or more serious injuries were the result of the unequal pressure of steam in different sections. There was no pipe connecting the steam chambers of the two boilers, and although the steam chambers were not connected the water chambers were, so that any increase of steam pressure in one boiler simply had the effect of driving the water out of its own chamber into the other boiler. Not only was the unprotected plate exposed to the fire, but the abnormal increase in the water level of one chamber held out every inducement to priming. This serious structural omission explains the bursting due to overheating, and at the same time the priming which occurred. It is very remarkable that the partial absence of a similar pipe contributed to the failure of the boilers of the *Montana*. It has been suggested that the bursting of the tubes in the *Propontis* arose, not so much from defective circulation of the water as from corrosion and consequent weakening of the plates; this is the fact as regards the small circular perforations, but the same explanation does not apply to the longitudinal rents, and is not borne out by an examination into the character of the larger fractures. The longitudinal rents which caused the loss of life occurred in portions of the tubes practically uninjured by corrosion; and it was found that the fractures showed only a slightly reduced thickness of metal, and that at a distance of about 1 inch from the lip of the rent the plates resumed their original thickness. The bursting pressure of the rent tube was, as already stated, 1,200 pounds per square inch, and the uncorroded appearance of the fractured portions points to the conclusion that defective circulation and overheating caused the explosions. The plates, if hot, would stretch a little before giving way, and the confined space over which the thinness extends seems to show that it should be traced to stretching only.

FIG. 5.



FRONT ELEVATION OF BOILER

The *Birkenhead* is one of the large passenger ferry steamers running between Liverpool and Birkenhead. She was built in 1872, and fitted by the Patent Steam

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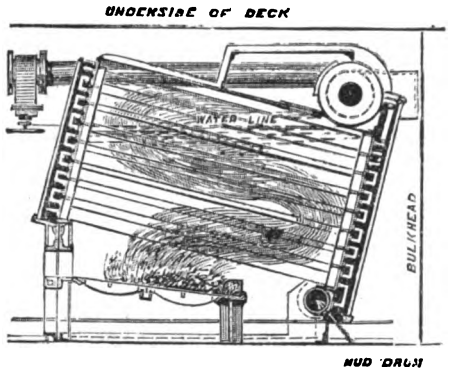
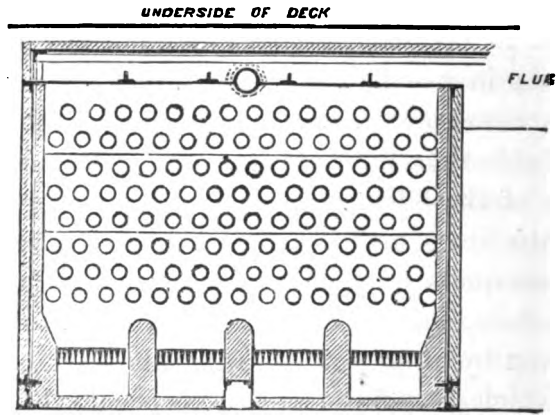
Boiler Company, Birmingham, with tubulous boilers on Root's patent. The boilers, Figs. 5, 6, 7, 8 and 9, were each divided into fifteen sections, each consisting of eight horizontally-inclined tubes 11 feet long by 6 inches diameter; these tubes were at the

FIG. 6



LONGITUDINAL SECTION

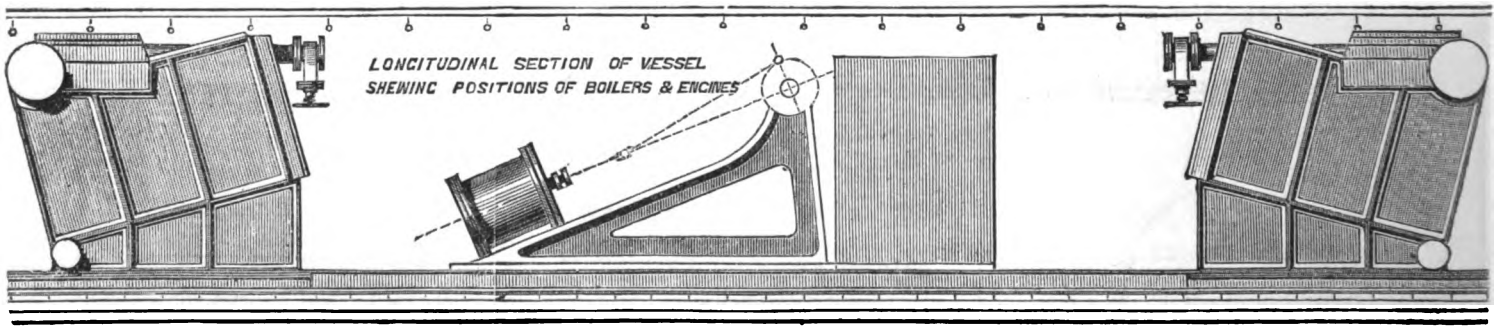
FIG. 7



SECTION THROUGH FURNACES

ends connected to small cellular vessels. Communication between these vessels in their respective horizontal tiers was effected by bent pipes bolted to them, as shown on the diagrams. The working pressure was 40 pounds, although in designing the boiler the pressure was intended to be 60 pounds. The course taken by the steam generated in the bottom tube to reach the steam reservoir at the top will be readily understood. It is only fair to the manufacturers to say that they laboured under the difficulty of a very confined head room; these vessels are of limited draught, and as a flush deck is

FIG. 8.



necessary for the passenger traffic, the vertical space at the disposal of the designer was quite insufficient to give boilers of this type a fair chance of success. The boilers were for the first few months of their existence worked with impure water, and considerable trouble from overheated tubes was the consequence. A fresh-water tank was afterwards fitted, and with an improved result; but still it was found that the tubes in the bottom

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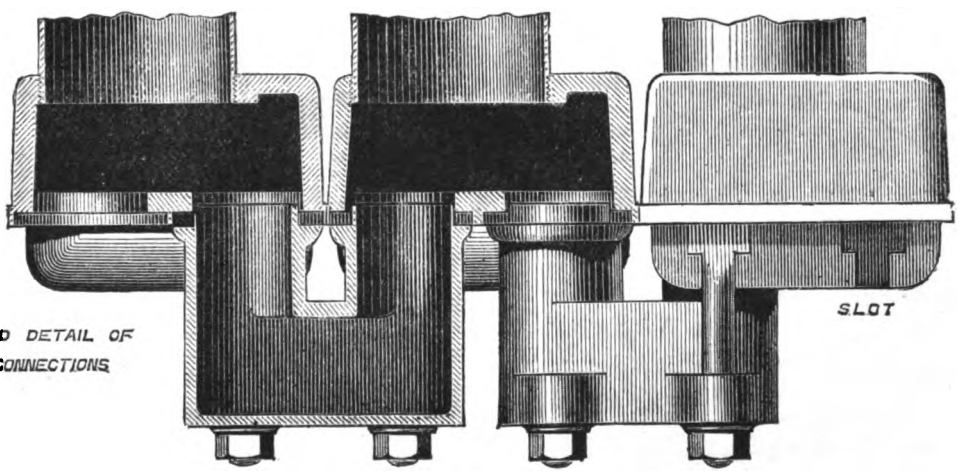
row were continually bulging and giving out from overheating, and the vessel was frequently off duty for repair. The exit of the steam was no doubt retarded by the turnings and counterturnings it underwent before reaching the surface. The greater vertical distance through which the steam rises from the surface of the water before rushing to the engine the less is the tendency to carry water away with it; not only because there is more time given for the water to fall back from the ascending steam, but because the pull caused by each stroke of the engine is less severely felt at the bottom tubes if they are some distance below the steam outlet. The diagram shows that in this design a very small height was between the stop valve and the bottom tubes, and the engines being paddle engines with large cylinders and slow stroke, there is no doubt that the tendency of the water to forsake the bottom tubes was greatly enhanced from this cause, although primarily due to imperfect circulation. This defect would

FIG. 9.



also be increased by the stoppages and lying-to of the vessel in her work as a ferry steamer, allowing accumulations of the steam pressure. Not only so, but the deficient room rendered it impossible to get in so much boiler power as was afterwards thought necessary; and the manufacturers allege that consequent forcing of the fire contributed in no small degree to the failure of the tubes. The sister ships to the *Birkenhead*, working on the same station and with very similar engines, but boilers of the ordinary type, offered an excellent standard of the average consumption of coal, and the saving in the *Birkenhead*, in comparison with one of the boats, amounted to 17 per cent., and by comparison with the other, to 25 per cent. This result is the more remarkable when it is remembered that the pressure was only 40 pounds, and that the expansion in the engines of the *Birkenhead* could not be greater than in the sister ships; the comparative economy was therefore entirely due to the more effective arrangement of the parts, the thinness of the metal in the tubes, and the direct action of the flame upon them

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favouring the evaporation; had the pressure been higher and the expansion greater the economy would no doubt have been largely increased. Notwithstanding the excellent result in point of economy, the Ferry management condemned the boilers after nearly three years' work, on account of the continual breakdowns, and the vessel is now fitted with boilers of the ordinary type made by Messrs. James Taylor and Co. The cause of the comparative failure of these boilers has already been indicated; the twisted passages for the exit of the steam and the low vertical height, added to heavy firing, caused the bottom tubes to be occasionally full of steam, and being exposed to the full action of the fire they were quickly destroyed.

Another vessel fitted with boilers on Root's patent, and of very similar design, but still more contracted passages for circulation, was the steam ship *Malta*, of 2,000

FIG. 10.

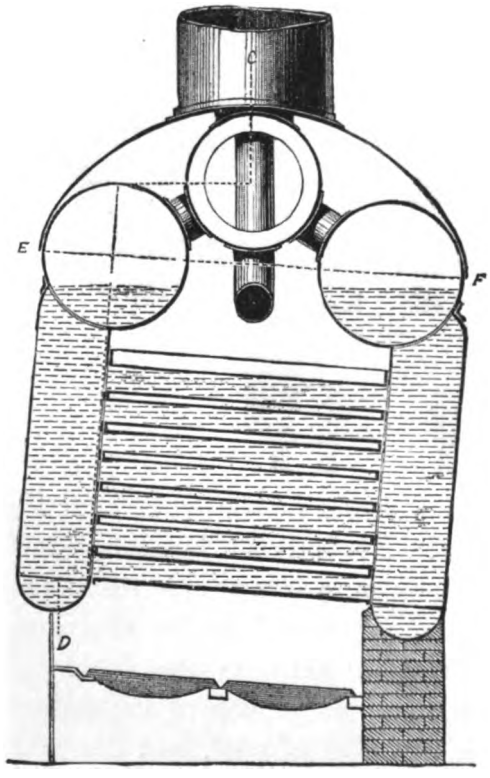
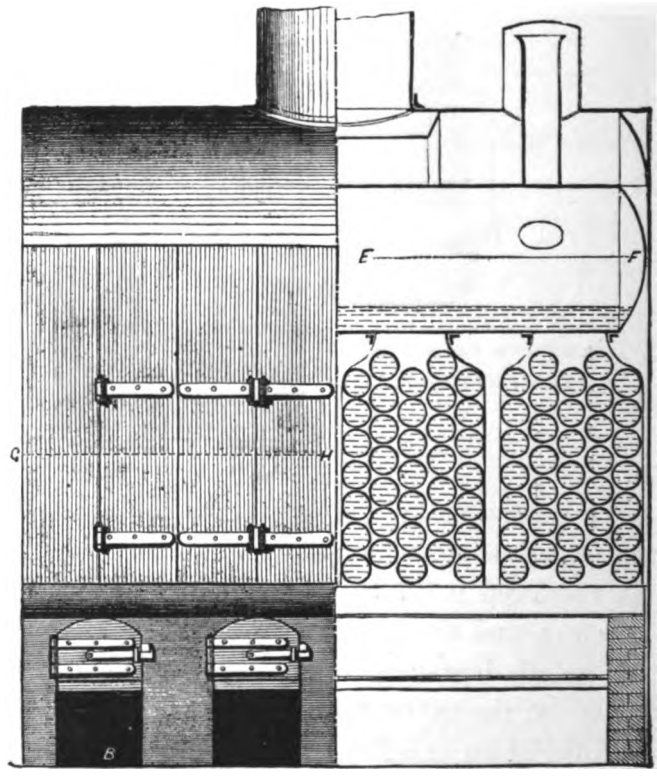


FIG. 11.



tons, belonging to the Merchants' Trading Company, Liverpool. They were in this case found to give off steam with great rapidity, and steam could be raised in them in about half the time necessary in boilers of the ordinary type. The working pressure was 50 pounds. The boilers went on about twelve months, during which time the vessel visited the Mediterranean and the Baltic. Very little priming took place, but

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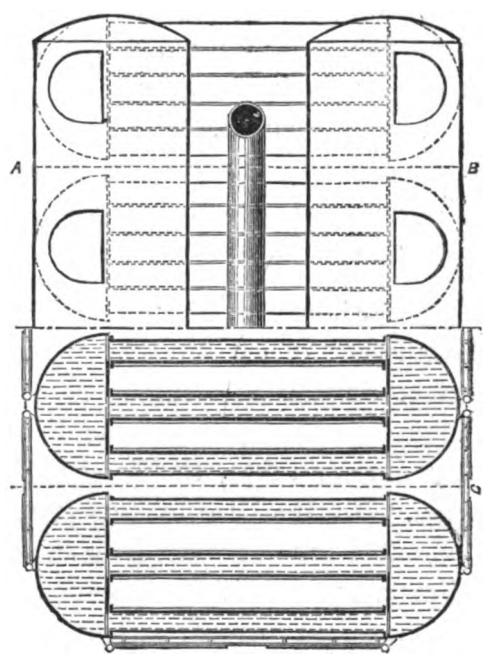
the same defect as in the other cases developed itself; the circulation of the water was insufficient, some of the bottom tubes nearest the fire bulged and gave out, and the boilers were finally taken out to convert the vessel into a sailing ship. The engines were very old before the Root boiler was fitted, and their worn-out condition contributed to the owners' decision to alter the vessel.

I am informed that many of these Root boilers of the same manufacture are working successfully on land, and where large space may be given, and leisurely delivery of the steam is possible, they have been found highly successful.

Figs. 10, 11, and 12 represent the system of boilers fitted to the steam ships *Amalia* and *Palm* under Ramsden's patent. These boilers worked very satisfactorily for about four years; but at the end of that time it was found that the construction of the boilers not fully providing means for the removal of the incrustation, the plates had seriously deteriorated, and the boilers were consequently removed.

FIG. 12.



Trials were made of the Howard patent safety boiler in the steam ships *Fairy Dell*, *Meredith*, and *Marc Antony*. These boilers were all constructed about the same date, 1870. Their working on board ship in all these cases was quite unsatisfactory; the lower tubes burst, others leaked, and very great priming took place. These results were traced to the same general causes that led to the difficulties experienced with the *Birkenhead* and *Malta*, and it is unnecessary to discuss them in detail.

After discussing so many failures of the water-tube system, I cannot close this Paper without describing the most recent working example of the tubulous boiler for marine purposes. One of the earliest advocates of the tubulous boiler is Mr. John Watt, of Birkenhead, and his system is shown in Fig. 13 which represents the boiler of the steam flat *Gertrude*. "The boiler consists of a series of inclined tubes connected at "their ends to rectangular water chambers. To the top of the chamber is a steam "receiver from whence the steam is taken to the engines. The rectangular chambers "are stayed like the ordinary locomotive fire-box, by means of stays through the door "and tube plates, one end of each stay being left sufficiently long to enable the tube

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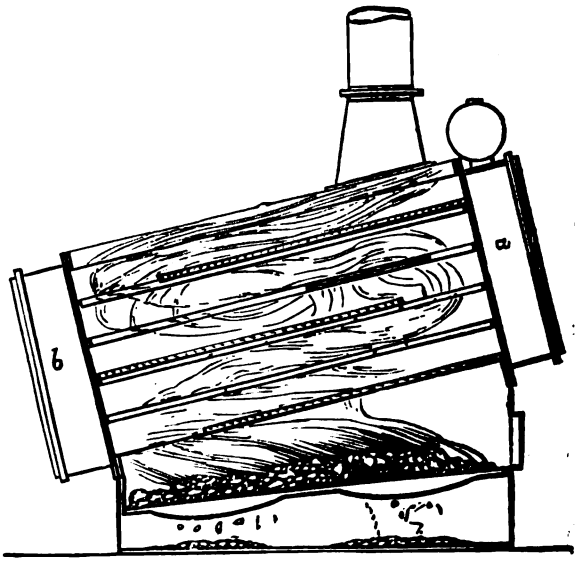
" doors to be secured. The tubes are in diagonal rows, and the course of the flame is " in zigzag direction amongst them." A very brief consideration of the natural action of the steam and water in this boiler will show that it possesses features superior to some of the boilers already described. As the steam is generated in the tubes, the angle at which they are inclined will facilitate its ascent to the upper rectangular water space *a*, and once there, its ascent to the steam receiver is easy and certain, its upward passage being unobstructed; at the same time the water to take the place of the steam generated contained in the lower rectangular chamber *b* will by a natural action ascend from it, and so a good circulation is secured. The necessary feature in a boiler of this arrangement is a separate outlet for the steam, and a separate inlet for the circulating water; any contention between the ascending steam and the descending water must be fatal.

FIG. 13.



The shorter and wider the tubes are made the greater will be their safety, because the amount of evaporation will vary as the heating surface of the tube. Now the surface of the tube increases directly as the diameter, but the volume contained increases in the square of the diameter, and this fact goes far to explain the danger of long narrow tubes, the length still further increasing the difficulty of the exit of the steam. In the case of the *Propontis* some of the smaller vertical pipes were so far attenuated as to be 8 feet long and $2\frac{1}{2}$ inches diameter. I am informed that the *Gertrude's* boiler has worked for some months, and with so perfect a circulation that no deposit or scale has been formed, although salt water is partially used and the engine is not fitted with a surface condenser.

Another design strongly advocated by the inventor is that of Mr. Wigzell's, shown in Figs. 14 and 15. It will be noticed that this is a compromise between the tubulous boiler and the boiler of ordinary type; the flame will surround the inclined cylinders, and the cylinders being perforated with tubes it will pass through these on its way to the chimney, its exit through them being made compulsory by blocking up the outer spaces between the cylinders by diaphragm plates. No boilers of this design have yet been tried at sea, though the inventor assures me that most satisfactory results are obtained by their use for land purposes.

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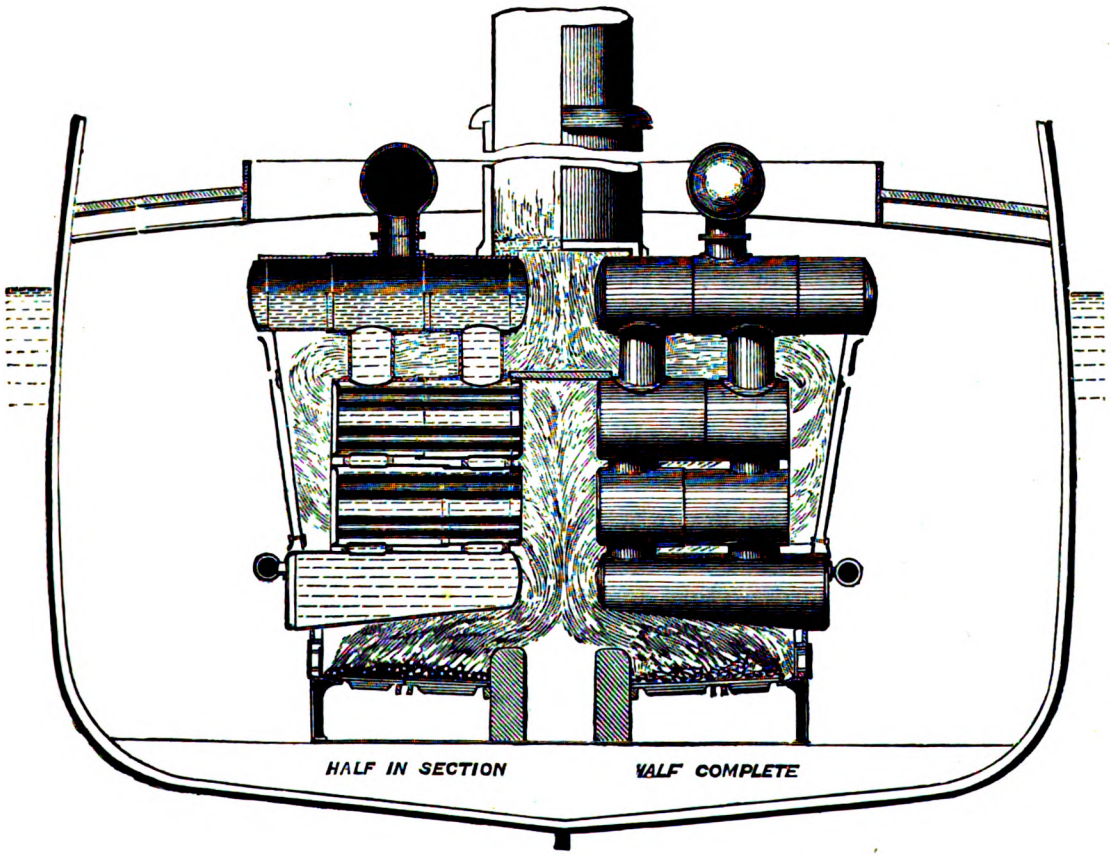
I set out with the statement that, so far as present lights enable us to judge, greater economy in the use of coal at sea can only be obtained by increased boiler pressure; that cylindrical vessels of small diameter are the only practical generators of high-pressure steam; that up to the present time no water-tube boiler on a large scale has given perfectly satisfactory results at sea; and that the practical trials already made are in themselves sufficient to teach useful lessons, and perhaps to indicate to some extent the practice of the future. If there is some specific feature in the design of the

FIG. 14.



boilers of the above-mentioned ships which is common to them all, and has contributed to their failure, then a valuable lesson will have been drawn from them. Insufficient circulation of the water has been more or less a characteristic of the above cases; and to get at the root of the matter it is necessary to discover why the circulation has been insufficient. In the ordinary boiler the reservoir for steam is vertically above the surface upon which it is generated, and no obstruction to its ascent is offered except the friction through the superincumbent water.

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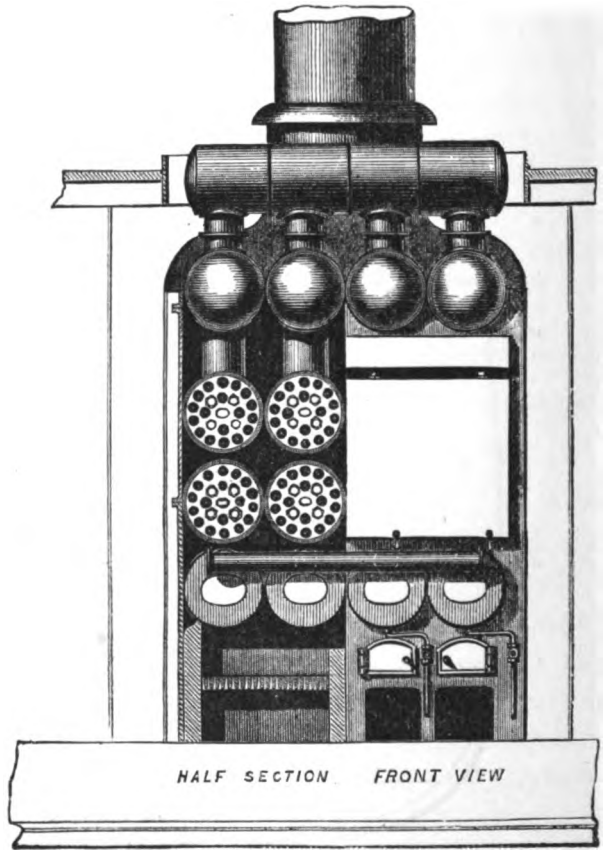
Looking at the diagrams, it will be seen that the steam generated at certain portions of the boiler surface, in all the examples of water-tube boilers, must travel a greater or less distance horizontally, or nearly horizontally, before it can make its movement in a vertical direction; and in some of the cases the steam encounters repeated obstructions to and horizontal deviations from its continued ascent through the water. No difficulty of this kind is to be found in the ordinary marine boiler; the steam as it is generated ascends by a free and natural action through an unobstructed body of water, and it is only when steam can move in a vertical or nearly vertical direction that it has any tendency to circulation at all. To design a boiler in such a manner that the steam shall move in a horizontal direction, for ever so short a distance, is to lay down a wrong principle, because the horizontal movement can only be borrowed from the force developed in those particles of steam which are ascending, and which jostle so to speak their neighbours along the horizontal portion of their journey. Now the greatest obstruction to circulation at high pressures, apart from the arrangement of the tubes, is the great friction. An arrangement which at a lower pressure would give fairly good results, will quite refuse to produce proper circulation when the friction is seriously increased by high pressure, and it is evident that a high-pressure water-tube boiler must, if it does not depend on artificial circulation, have no portion of its interior so arranged that a horizontal flow of the steam through the water is necessary. The features which the successful marine high-pressure boiler must possess are, a clear vertical lead for the steam as it is generated, separate downcasts for the water and upcasts for the steam, and accessibility for the removal of incrustation. Whether the designs introduced, but not yet fully tested, may be found to give better results than some of those we have named is a problem yet to be solved.

FIG. 15.



I have to express my thanks to the various manufacturers and other gentlemen who have assisted in the preparation of this Paper; and having briefly reviewed some of

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the principal experiments already made at sea with the tubulous boiler, it remains to say that the Admiralty is now engaged in a trial of the high-pressure boiler on Perkins's system, and no doubt the results will in due time become generally known. It is a matter of great congratulation to the engineering profession generally that the eminent Engineer-in-Chief of the Navy has taken so bold and enterprising action as to advise this interesting experiment.

So far as we may now judge, it does appear that the water-tube boiler, designed scientifically and in accordance with the experience the past failures have taught, holds out prospect of much more satisfactory and profitable work than has yet been obtained by its use at sea.

DISCUSSION.

Rear-Admiral J. H. SELWYN, R.N.: I have long taken a very great interest in this subject, as being the real basis of the whole question of thermodynamics as applied to ships at sea. It is perfectly clear that in vain we seek such small gains or such small economies as have been adverted to by Mr. Griffiths, while we neglect the enormous economies known to be possible simply from want of consideration of the question how best to heat water. I have followed for a very long time the question of tubulous boilers. The boiler to which my attention was first drawn by Mr. Field still remains, as regards land boilers, the type of successful tubulous boilers. That boiler is employed in all our fire engines to-day, and it does entirely fulfil the conditions laid down by the author of the Paper; and I think it perfectly reasonable to suppose, as we look for safety and efficiency to perfect circulation, and that circulation is only to be obtained by vertical action, that there must be a distinct division between the ascending and descending currents. The next question is whether there is any real difficulty in providing for the difference between the fresh water that is used in our land fire engines and the salt water we have to use in marine boilers—is there anything in the nature of the incrustation, or the nature of the water used, which will prevent us from adopting the same plan as answers with them? I think most people know that seven minutes suffice to raise water from the ordinary temperature of the atmosphere to steam at 40 pounds pressure with the Field Fire-Engine Boiler. That alone is quite sufficient to show what is going on inside. But the question that is first to be solved is that to which the late lamented Professor Macquorn Rankine drew attention, depending on the fact that the temperature of the water surrounding the fire in every boiler is to the temperature of combustion almost absolutely cold. No matter what may be the temperature of water in the boiler due to the pressure, yet to the temperature requisite for perfect combustion the surrounding walls of your combustion furnace are comparatively cold; and under those conditions no perfect combustion can be expected without adding an enormous quantity of oxygen for draught beyond what ought to be required for the proper combustion for the hydro-carbon present, and losing an immense quantity of heat up the funnel, scarcely ever amounting to less than 600 degrees, by reason of the increased rapidity of that draught forced in. I will just show you

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in a few words what this amounts to. Coal properly burnt—that is to say, burnt as chemists can do it in laboratories—will give you 15 pounds of water evaporated for every pound of carbon; but we do not get at sea 7 pounds as an ordinary result. I do not say that it is not sometimes exceeded. We get 70 pounds pressure in the boiler and with what result? We get for indicated horse-power 100, as shown us to-day, effective horse-power 35.* I ask you, Gentlemen, just to investigate the wretched result—the terrible loss that has taken place between those two points of effective horse-power and fuel expended. If you want to have a boiler made up of tubes, in which the water contends with the steam, I say distinctly it is utterly and totally impossible to get a good result; for the sooner you begin to generate steam the sooner will you drive away the water from those surfaces by means of which you have generated the steam. There must be therefore perfect circulation. It has been remarked that as we approach high pressure the large boilers we have hitherto used become almost impracticable, if for no other reason than that the surfaces require to be heavily stayed, so as to take up a large portion of the boiler surface. The horizontal-tube surface has never been accepted among engineers as by any means entirely efficient—leaving aside the question we have been speaking of—for bringing down the heat of combustion below that at which combustion can take place. Only the upper surface of the tube has ever been accepted as the true heating surface, and that is the very first surface which after short experience at sea becomes so coated with scale as to be practically inoperative. Therefore you ought to abandon all ideas gathered from your old boilers the instant you resort to higher pressure. If I speak strongly on this subject it is because I am the only person I may say who has stood up in this Institution and shown that fuel could in actual practice on the large scale be made to produce—when its calorific value theoretically so called was 17 pounds—a measured evaporation of 16 pounds of water with every pound of fuel; and I say you will do very wrong indeed if you sit down satisfied to put the boiler question on one side as a secondary consideration, or leave it in hands which so maltreat it as I am sorry to say most of the examples before us show has been done. Devote your whole attention as engineers to the primary condition—to the heart, as I may call it—which is the generator of the whole circulation of the steam. The boiler of to-day is objectionable in a variety of ways. The author of the Paper has strongly pointed out how impossible it would be to repair those boilers without cutting our ships to pieces. We cannot get them through the iron decks to repair them, if we have iron decks, without cutting these to pieces. We can carry tubulous boilers, properly made in parts to sea, with the great probability of being able to repair them, even at sea, should such an occasion arise; but the main point to which I wish to direct the attention of the Meeting is the infamous loss of heating power to which at present we have to submit.

Mr. Thomas Moy: I could say a great deal on this subject, because I have tried many experiments on tubular boilers; but as I have to bring before you to-morrow an engine constructed on this very principle, I will reserve my remarks until then.

Mr. Mac Farlane Gray: I have at different times had to turn my attention to questions in connection with such boilers as these. What calls for such boilers is the great expectation which engineers, practical and amateur, have entertained of the great increase of economy to be arrived at by increased pressure. Now I hold an opposite opinion to that. I some time ago made a statement upon the subject

* Thus 50 per cent. of the heating power of the fuel is wasted mainly by imperfect combustion, and 65 per cent. of the indicated horse-power by friction and slip, &c., leaving 18 per cent. of the fuel effectively employed. Even this is much higher than ordinary practice.—J. H. S.

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consisting of a sentence or two which I will repeat here. Mr. Alfred Holt—than whom no man in the world has a greater knowledge practically of what has been done by steam and by engines afloat—stated as a reason why the Board of Trade ought to allow shipowners increased pressure, in effect this: "Comparing the position of the shipowner now with what it was twenty years ago" (he referred to the time before the recent alterations in engines, compounding and surface condensation), "we stand thus—"that we then got for a certain quantity of coal five horse-power, and we get now eight horse-power from "the same quantity; remove the restrictions on pressure, and we might double this economy." I think that is a moderate estimate and is about right; and if you go to those who have to pay for the coal and to work the steamers you will find all that can be said is that engines have within the last twenty or twenty-five years increased the horse-power obtained from a given quantity of coal from 5 to 8. Now let us divide that into steps. The first step was that we introduced surface condensers which increased the 5 to 6. Let us begin at that 6 now. Then, the boiler pressure was 25 pounds on the square inch, 15 pounds added to that gave us 40 pounds absolute pressure, and at that pressure we had six horse-power for that certain quantity of coal. To-day we are working with 65 pounds pressure on the boiler, and 15 pounds of atmosphere, and that makes 80; and what are we obtaining? We get 8. What have we done? We have added 2 to the 6, which gives 8; we have multiplied the 40 pounds by 2 and get 80 pounds pressure. Now investigate this question thermodynamically, theoretically, practically, or in any way you like, you will never make more of it than this—that just as you double you have to add; the horse-power increases in arithmetical progression, and the pressure in geometrical progression. Now follow that a step or two. It is said that if the Board of Trade would allow us higher pressure we could undertake to double the economy to-morrow. Where should we be then? Twice 80 is 160; 2 and 8 are 10; at 145 pounds on the boiler you will just get ten horse-power instead of eight, supposing no new drawback be introduced. Now carry it up 2 and 2 and 2 to 16 and see what pressure you would require before you get to that. It would require 1,280 pounds on the square inch to double the present efficiency even if that pressure could be carried without additional drawback. A gentleman, who is interested in water-tube boilers, two days ago was arguing this point with me, and he put it in words that agree with the views which many of you have upon this subject. He said, "Why I go in for such high pressure is this—I have found that "with every increase of pressure in a locomotive boiler there has been an increase "of economy." I said, "But our marine engines are now working at a far higher "pressure than locomotives were ever worked at" (and this is a point generally forgotten in comparing the two); the pressure *in respect to economy* must be measured by what multiple the initial pressure is of your terminal pressure. The least terminal pressure you can have is the back pressure. In the marine engine of to-day we have a back pressure of 3 pounds, and we are working with 80 pounds gross, beginning with a pressure which is say twenty-five times our lowest pressure. In the locomotive the least terminal pressure we can have is the back pressure: it must be the atmospheric 15 pounds, and at least 1 pound—that is 16; and 16 times 25 is 400; but there is no locomotive working at 400 pounds pressure. When the locomotive gets up to 400 pounds pressure it will then have got to about the same pressure *in respect to economy* that we are now at in the marine engine. Now there is one other point in reference to this boiler. What has destroyed many of these boilers is the fracture of the plates by contraction. I think the author of the Paper

40	6
× 2	+ 2
80	8
× 2	+ 2
160	10
× 2	+ 2
320	12
× 2	+ 2
640	14
× 2	+ 2
1280	16

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referred to in the *Nautical Magazine* made of too little importance the question of range of temperature. In the *Montana* one of the pipes cracked—not when it was at work, but when it was cooling down. In the *Marc Antony*, which has been referred to in the Paper, the Engineer said, "I used to frighten "them out of the stoke-hole; all I had to do was to open a furnace door suddenly, and immediately 'pop' "went a tube in the boiler." This was due to the mere change of temperature. It was not because the temperature of the iron was so very high that it broke, but it was the change of temperature in its getting colder. Now we have a lot of tube plates always cracking by being overheated it is said, but there never was a tube plate cracked by being overheated. It is not by being overheated, but it is in the cooling that it cracks. In overheating the part stumps itself up, and makes itself so short to accommodate the colder adjacent parts, that when it has to cool it breaks rather than stretch again. Now there is a certain range of temperature through which the parts of a boiler must be heated, and there is a head of temperature required to drive a certain quantity of heat through a plate into the water, and of course the higher the temperature of the water is the higher must the temperature of the plate be. However you construct a boiler, when that boiler is blown off, and when it has cooled, it comes back again to the low normal temperature of, say, 60 degrees; and with great range of change, unless all the parts of the boiler are simultaneously coming through the same range of temperature, which with a possibility of a deposit of solid matter is nearly impossible, it requires very great engineering care to ensure that one part does not break the other.

Mr. J. FORTESCUE FLANNERY: May I venture to ask Mr. Mac Farlane Gray one question? Did I understand you to say that this Paper contained any statement that the economy increased directly in the same ratio as the pressure increased? That is not so.

Mr. MAC FARLANE GRAY: I did not say that at all; but I meant to have said that I was so struck with the excellence of this Paper and with the remarkably clear way in which it was read, that it was a pleasure to listen to it. I think it would be worth while for the Institution to pay the expenses of the beautiful drawings which are exhibited here in relation to this subject.

Mr. C. KNAPP: With your kind permission, Gentlemen, I would make a few remarks upon the subject of tube boilers as fitted in the *Birkenhead*, having been intimately connected with their construction, and also having regularly examined the boilers from the date they were put in until the date when they were taken out. In the first onset it was intended to be a boiler of 60 pounds to the inch, and the steam was to be carried one-third of the stroke. For certain reasons that was not found practicable, and instead of that we have 40, or 35 and ⅔rds. Now we all know that that must give a bad result with boilers of this description constructed as I have said, and made to work at less than one-third. I will state what was the cause of the boiler bursting, and many of the mishaps are owing thereto. The cause of the failure of the tubes I do not attribute to defective circulation, but I attribute it to the same action as has been described as taking place in the *Propontis*. If all the tubes had been taken out I should not think there would have been six doubtful tubes; and it was not clearly shown that it was owing to the heating. Another head of difficulty we had to contend with was that we were not marine engineers, and the long boiler on Root's patent was put into the ship; and the requirements of a marine boiler being different from the requirements of a land boiler the contractors were not up to it. They were not aware of it, and did not know their business. In fact they acknowledge it, and to that was owing much of the failure of Root's boilers. With your permission I would just mention the state of the new

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patent boiler at the present moment. We have now entirely overcome a great drawback mentioned before, which was the accumulation of steam in the tubes. For the last four years I have never come across a single case where we have had that. We have got the proper ingress for our water into the pipes, and the proper egress for the steam. If that were not the case would the economy that has been stated to have taken place in the *Birkenhead* have resulted? Would tubes now, when containing steam, be exposed to fire for three hours or six hours even, without burning through when the tubes were only $\frac{3}{16}$ths of an inch in thickness. I think these facts will prove that the tubes really contain water and not steam. The economy that has been mentioned we also find in land boilers. By very careful experiments made by engineers we have found that with the best constructed land boilers there is about 10 per cent. saved. We do not go in for 30 or 40 per cent., but we say 10 per cent. That is certified. On the other hand in Germany our boilers are regularly tested by the German Government to work up to 150 pounds, and we never have had an accident to any of these boilers. The tubes have failed through bad workmanship, or accumulation of scale, or other defects, but we have never had damage done to anything beyond the tube itself. Cast-iron heads and caps have also been objected to; but really the fact remains that we have never had accidents; and surely if that is the case then for the Board of Trade to object to cast-iron heads and caps is not, as I submit, a just objection. As a proof of the value of the boilers there are many people in this country who had the boilers five or six years ago, and these people have been continually ordering the boilers. They have tried them and some have now as many as fifteen or sixteen boilers, and all those firms are satisfied. I therefore submit that these boilers are suitable for land purposes, and I should think that marine engineers could also make them suitable for marine purposes. We ourselves—I speak of the makers of the boilers—believe that we are able to overcome, or have overcome, all the difficulties that we once had to contend with; but the fact of the matter is that we are not marine engineers who believe them valuable for marine engines, and we should be most happy if the matter were taken in hand. I thank you, Gentlemen, for the indulgence you have afforded me.

Mr. J. Wigham Richardson: It would be interesting to the Meeting if Mr. Mac Farlane Gray would state, as we are all interested in the subject of the different pressures, what is the theoretical saving as between 75 pounds pressure of steam and say 100 pounds, supposing you expand the steam down to the same temperature as the steam enters the condenser. I believe he can give us that information.

Mr. Mac Farlane Gray: It is only a very small per-centage. I cannot say exactly off hand. At Stockton Mr. Blair got up to 100 pounds after having from me the table of twos. I asked him afterwards if he had expected more. He said, "The result was I did not get as much as you told me."

Mr. J. Fortescue Flannery: I do not know that there are many points, Gentlemen, I can say much about. The first speaker alluded to a well-known and fully-recognised fact, that we only get one-tenth practically of the theoretical calorific energy of the coal; and it is the earnest desire of all marine engineers to increase the practical effect from the coal. I am very glad that Mr. Gray has pointed out that the increase in the economy is not directly the same as the increase in the temperature or in the pressure of the steam. I did not at all mean to convey that, and I am very glad that Mr. Gray did not credit me with the intention of conveying it. I have desired to emphasize the fact that the higher the pressure the greater the economy. Of that there cannot be any doubt. I am also glad that Mr. Gray very frankly admits that the conclusion he drew from the failure of the *Montana* boilers was not quite the conclusion which on further consideration he is inclined to draw.

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The CHAIRMAN: Gentlemen, I am sure we are all much indebted to Mr. Flannery for having brought before us in so very clear and interesting a form such an important subject, and I presume you will all give him your thanks for the Paper which he has read this evening.

Mr. MAC FARLANE GRAY: I did not mean to say that the cause of the failure of the *Montana* boilers was not what I said it was. I said that I should have been inclined to pay more attention to, and to have brought more prominently forward, the other consideration of temperature.

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ON SOME TRIALS OF SIMPLE AND COMPOUND ENGINES.*

By Richard Sennett, Esq., F.R.S.N.A. and M.E., Assistant to Chief Engineer, Devonport Dockyard, Member.

[Read at the Seventeenth Session of the Institution of Naval Architects, 7th April, 1876; Vice-Admiral Sir F. W. E. Nicolson, Bart., C.B., Vice-President, in the Chair.]

During the last Session of the Institution I had the honour of reading a Paper on "Compound Engines." In it I endeavoured to show that compound engines were, both in theory and in fact, more economical and more suited to the present requirements of engineering than simple expansion engines. In the last paragraph in that Paper I referred to some engines, simple and compound, then in course of construction for the Admiralty, the trials of which would probably throw some light on the comparative merits of the two systems. Since that time three sets of engines of 360 indicated horse-power, two with simple expansion, for the gun-vessels *Sheldrake* and *Moorhen*, and one compound for the *Mallard*, have been completed, and the official trials made at Devonport. No special trials were made to ascertain the total quantities of water required per indicated horse-power, in the two classes of engines, as the ships proceeded to their destinations as soon as they were completed, so that there was no time for experiments. I have thought, however, that a few particulars of the engines and the results of their measured-mile trials, with the quantity of water used by each, as computed from their indicator diagrams, would perhaps be interesting to the Members of this Institution, and it will be seen that the results obtained agree very closely with those given in my Paper of last year.

The machinery and boilers of the *Sheldrake* and *Moorhen* were constructed by Messrs. Napier and Sons, of Glasgow, and the *Mallard's* machinery and boilers by Earle's Shipbuilding and Engineering Company, Hull. The boilers in all three ships are practically the same, the only difference being that the tubes in the *Mallard's* boilers are $2\frac{3}{4}$ inches diameter, whilst in the *Sheldrake* and *Moorhen* they are $2\frac{1}{2}$ inches. The boilers are cylindrical, each containing two cylindrical furnaces, 2 feet 6 inches

* Received 4th April, 1876.

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diameter, and 4 feet 6 inches long. These two furnaces terminate in a common combustion chamber, 3 feet 2 inches deep. The tubes do not return over the furnaces, but are continued from the combustion chamber to the smoke box at the forward end of the boiler, the boilers being placed in a fore-and-aft direction. On the top of the combustion chamber, between the ends of the furnaces and the tubes, is suspended a bridge, which deflects the flame and heated gases before they enter the tubes, the use of which has been attended with satisfactory results.

The engines of the *Sheldrake* and *Moorhen* are simple expansion engines direct-acting, the connecting-rods working between the cylinders and the cranks. Both cylinders with their ends and covers are jacketed with steam of the full boiler pressure. Expansion valves, capable of cutting off the steam as early as one-fifteenth of the stroke, are fitted on the backs of the main slide valves, and are worked by means of eccentrics on the crank shaft, the different grades of expansion being regulated by links. The surface condenser tubes are horizontal, and the feed pumps take their supply direct from the hot well, no feed tank being fitted. The condensing water is circulated through the condenser around the tubes by means of a centrifugal pump, the diameter of the circulating pipes being $6\frac{3}{4}$ inches.

The engines of the *Mallard* are compound, with return connecting-rods. The piston-rod of the low-pressure cylinder is taken through the cylinder cover at the back, and a slipper guide is attached to it for the support of the piston. The barrel and both ends of the high-pressure cylinder are jacketed with steam of the full boiler pressure, and those of the low-pressure cylinder with steam at a pressure of 30 pounds per square inch. Gridiron expansion valves, arranged to cut off the steam as early as $\frac{1}{8}$th of the stroke, are fitted to work on faces at the tops of the slide-jackets of both high and low-pressure cylinders, and are worked by eccentrics on the crank shaft, with links to regulate the grades of expansion. The surface condenser tubes are horizontal, as in the *Sheldrake* and *Moorhen;* but the condensed water passes from the hot well into a wrought-iron tank, from which the feed pumps draw their supply for the boilers. The condensing water is circulated around the tubes by means of a centrifugal pump, the diameter of the circulating pipes being 7 inches.

The weights of all three engines are practically the same, being between $77\frac{1}{2}$ and 78 tons; but the cost of the simple expansion engines was somewhat in excess of that of the compound engine. The principal particulars of the different engines and boilers are given in Table I., and it will be seen that the only practical difference between them is that one is a compound engine and the others simple expansion engines. Any difference in the results obtained may, therefore, be fairly attributed to the difference in the system of construction, and not so much to any difference of detail. In the cases

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under consideration the simple engine had however some advantage in this respect over the compound engine. In the *Sheldrake* and *Moorhen* the length of stroke and speed of piston were greater than in the *Mallard;* and the exhaustion valves of the simple engines were fitted to work directly on the backs of the main slide valves, whilst in the *Mallard* they were ordinary gridiron valves working on seatings on the tops of the slide-valve chests, so that the loss from clearance would be greater than if the valves had been fitted as in the *Sheldrake* and *Moorhen.*

TABLE I.—PRINCIPAL DIMENSIONS OF THE MACHINERY AND BOILERS.

	Sheldrake and *Moorhen.*		*Mallard.*	
	Simple Expansion.		Compound.	
	No.		No.	
Boilers—	2	...	2	
Diameter	...	6 ft. 6 in.	...	6 ft. 6 in.
Length	...	15 ft.	...	15 ft.
Furnaces—	4	...	4	
Diameter	...	2 ft. 6 in.	...	2 ft. 6 in.
Length	...	4 ft. 6 in.	...	4 ft. 6 in.
Surface	...	45 sq. ft.	...	45 sq. ft.
Tubes—	264	...	236	
Diameter (outside)	...	$2\frac{1}{2}$ in.	...	$2\frac{3}{4}$ in.
Length	...	6 ft.	...	6 ft.
Surface	...	1,036 sq. ft.	...	1,020 sq. ft.
Funnel—	1	...	1	
Diameter	...	2 ft. 6 in.	...	2 ft. 6 in.
Length (above fire grate)	...	36 ft.	...	36 ft.
Cylinders—	2	...	2	
Diameter	...	32 in.	...	high 31 in. low 48 in.
Stroke	...	1 ft. 9 in.	...	1 ft. 6 in.
Condenser tubes—	1,102	...	1,030	
Diameter (outside)	...	$\frac{3}{4}$ in.	...	$\frac{3}{4}$ in.
Length	...	3 ft. 6 in.	...	4 ft. 3 in.
Surface	...	757 sq. ft.	...	860 sq. ft.
Diameter of crank shaft	...	$7\frac{1}{4}$ in.	...	$6\frac{3}{4}$ in.
Ditto of screw ditto	...	$6\frac{3}{4}$ in.	...	$6\frac{1}{4}$ in.

The ships were all completed at the close of last year, and the performances taken for comparison are those on the measured-mile trials, when the machinery was in charge of the contractors themselves. The results of these trials, with some deductions therefrom, are given in Table II.

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TABLE II.—RESULTS OF PERFORMANCES ON THE MEASURED-MILE TRIALS.

	Sheldrake.		*Moorhen.*		*Mallard.*	
Date of trial	8th Sept., 1875.		9th Dec., 1875.		21st Dec., 1875.	
Draught of water ...	6 ft. 6 in. forward. 10 ft. 0 in. aft.		6 ft. 4 in. forward. 10 ft. 0 in. aft.		6 ft. 9 in. forward. 10 ft. 1 in. aft.	
Wind—						
Force	2		4		2 to 3.	
Direction	North.		N.N.E.		S.W.	
Sea	Smooth.		Smooth.		Smooth.	
Load on safety valves ...	60 lbs.		60 lbs.		60 lbs.	
Weather barometer ...	29·95 in.		30·56 in.		29·98 in.	
	Full Power.	Half Power.	Full Power.	Half Power.	Full Power.	Half Power.
Pressure of steam in boilers	62·35 lbs.	53 lbs.	63·5 lbs.	41 lbs.	58·4 lbs.	59 lbs.
Mean vacuum in condensers	20 in.	24 in.	23·3 in.	24·4 in.	23·75 in.	25·1 in.
Mean revolutions per minute	115·5	84·7	121·3	92·9	124·8	98·8
Indicated horse-power ...	367	137	387	180	398	213
Speed of piston per minute	404 ft.	295 ft.	424 ft.	324 ft.	374 ft.	296 ft.
Speed of ship ...	9·251 knots.	7·232 knots.	9·634 knots.	7·899 knots.	9·894 knots.	8·415 knots.
Water used per hour ...	7,900 lbs.	3,476 lbs.	7,780 lbs.	4,433 lbs.	6,844 lbs.	3,762 lbs.
Ditto per indicated horse-power per hour ...	21·5	25·4	20·1	24·6	17·12	17·66

All the trials were made over the measured distance inside the Plymouth Breakwater, and the conditions of trial in the three cases were as nearly as possible the same. The trials were not specially made with a view to economy, but so far as our present purpose is concerned this is not of much moment, since the comparison is based on the quantities of steam used in the cylinders, as shown by the indicator diagrams (Plate XX.), and on the indicated horse-power actually developed. The amount of water used per indicated horse-power per hour given in Table II. does not represent the whole of the steam used in the engines, for to this must be added the amount lost by liquefaction in the cylinders, jackets, &c. Experiments have however shown very conclusively that the loss from these causes is greater in the simple expansive engine than in the compound engine, so that if the total quantities of water used had been measured, the comparison would probably have been still more unfavourable to the simple engine than that shown in Table II. The results from the *Sheldrake* and *Moorhen* appear to confirm each other, and agree very fairly with those from the *Swinger* given in my Paper last year. The results from the *Mallard* are also very nearly the same as those from the *Goshawk* given in my

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last year's Paper, so that I think the figures given may be taken as being substantially accurate. It will be seen that in the *Moorhen* and *Sheldrake* the consumption of water per indicated horse-power was greater at half-power than at full power, whilst in the *Mallard* it was practically the same at both powers. The consumption of water in the compound engines of the *Mallard*, as estimated from the indicator diagrams, was at full power 17·12 pounds per indicated horse-power per hour, whilst the mean of the consumption at full power in the *Sheldrake* and *Moorhen* was 20·8 pounds, or 21·5 per cent. in excess of that in the compound engine. At half power the expenditure in the simple expansive engine was 41·5 per cent. greater than in the compound engine; the consumption of water in the *Mallard* at half power being 17·66 pounds per indicated horse-power per hour, whilst the mean of the consumption in the *Sheldrake* and *Moorhen* at half power was 25 pounds.

I may add that these results are corroborated in a general way by the coal consumption on the six hours' full-power trials at sea made by the officers of the ships after they were commissioned, the consumption of coal in the *Sheldrake* and *Moorhen* being considerably in excess of that in the *Mallard*. With reference to the objection that is sometimes urged as to the extra complexity of the compound engine, and the additional repairs it would probably require, I can only say that I see nothing whatever to justify such apprehension. There need be no additional complexity introduced into the compound engine, all the working parts of which are the same as in any other engine. The only difference is that the steam, instead of going direct from each cylinder to the condenser, passes from the high to the low-pressure cylinder, and from thence to the condenser. There is, so far as I know, no reason to apprehend that the compound engines in the *Mallard* will require more or earlier repair than the simple expansive engines in the *Sheldrake* or *Moorhen;* and they have this advantage, that as the engines wear, and the slides and pistons leak, the loss will be less in the compound engines than in the others, for the steam must in the compound engine pass two valves and two pistons before it can reach the condenser, and any leakage from the high-pressure cylinder has a chance of being utilised in the low-pressure cylinder. It is therefore reasonable to suppose that when the engines become worn the difference in economy will be increased instead of decreased. The accompanying indicator diagrams (Plate XX.) are copies of some taken on the trials under consideration, the necessary particulars being marked on the diagrams themselves.

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ON THE LONGITUDINAL GIRDER OR BULKHEAD SYSTEM OF IRON SHIP CONSTRUCTION.*

By Edwin W. De Rusett, Esq., A.I.C.E.

[Read at the Seventeenth Session of the Institution of Naval Architects, 8th April, 1876; the Right. Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

I suppose that there are few mercantile steamers afloat which would ever reach port if a hole 12 inches in diameter were punched in their after-hold when at sea. The pumps would be totally inadequate to clear the vessel of water, which would rise as the vessel settled down until it overtopped the water-tight bulkheads, thence on to the main deck, and so have access to the whole of the vessel, which could not fail to be speedily overwhelmed and become an easy prey to the surging seas. Or if the side was similarly pierced in the engine or boiler rooms, the most efficient means for clearing her of water, and the power which might speed her course to some friendly port, would soon be quenched, and the vessel become as helpless as though the whole of the bottom had been damaged, and this in spite of her other bulkheads—remembering that the measure of safety of any structure depends not upon the strong but the weak points of that construction. These remarks are by no means theoretically based, as they can be verified by calculation, and more cogently by the evidence of facts; and not more strikingly perhaps than by reference to the painful loss of the steam ship *Strathclyde*, which so quickly foundered after collision, with the loss of so many precious lives, in broad daylight and in fine weather. The general distrust, too, in the value of water-tight bulkheads, as a reliable means of safety to a severely-damaged vessel, seems to have prevailed on board the steam ship *Franconia*. And can this distrust be wondered at when the melancholy record of the Registrar of Shipping for the year 1874 and the first half of 1875 has left its impression on the minds of the people? He, when treating of all classes of British vessels, shows that 2·98 per cent. of all the vessels classed at London Lloyd's have foundered or are missing, and 5·51 per cent. of vessels unclassed at London Lloyd's, including those classed by other Societies, have shared the same fate.

* Received 6th March, 1876.

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These figures exclude all vessels known to have been stranded or lost through collision or other causes. Notable losses, as the *Ville du Havre*, &c., may be still fresh to many minds. And again, we must consider that many a long narrow steamer is almost entirely dependent on her engines—her sticks of masts and often low engine-power rendering her even laying to in a gale a matter of difficulty—and should the engine break down or the screw become fouled, it is difficult to conceive how the vessel could live out a storm when thus disabled. In the recent able Address of the President of the Institution of Civil Engineers occurs the following remarks which bear on this subject. When referring to the number of steamers bound to the Baltic and Mediterranean foundering during the passage of the North Sea and Bay of Biscay, he says:—"The "accidents have frequently been attributed to overloading. I am obliged to confess that "in a great number of instances overloading does not, to my mind, satisfactorily account "for all such disasters. The mercantile steamer of the present day is built long and "narrow, with large openings in the deck for engine-room skylight and stoke-hole. "The great length in proportion to breadth prevents her being hove to so closely as a "sailing ship, unless she is helped with enough steam to keep her head up to the sea. "Therefore an accident occurring to the engine is followed by the long steam ship falling "off the wind, which has the effect of bringing her broadside to the sea. She is "then exposed to the full force of the waves, and before any repairs of the engines can "be effected the sea often breaks into the engine room, rises to the furnaces, puts out the "fires, and leaves her helpless, or at all events only dependent on canvas, which will "not enable her to face the heavy seas."

The effect of such losses does not stop here, for they cause the insurance premiums to rise, increase the cost of all classes of goods by transit and loss, and thereby indirectly tend to make the necessaries of life more difficult of attainment.

I believe that some of these losses of steam ships are the results of weakness of design or construction, and my opinion is somewhat confirmed when I note the results of the calculations of Messrs. Mansell & John, and the teaching of the valued Papers of Mr. J. Wigham Richardson and others. Mr. William John, when treating of the strength of iron steam vessels built probably three years ago, shows that vessels of first-class construction, of 3,000 tons and upwards, when poised on the crest of a wave equal to the ship's length, have a factor of safety of $2\frac{1}{2}$ only, or about half of that considered necessary for structures on land, such as bridges, which have no such variable loads as a ship has to bear, neither are they subject to the sudden additional strains of immense masses of water heaped on them, or the strains consequent on varied immersion of the hull at sea, now buoyed up at the ends tending to double up the vessel, then as the wave sweeps along to midships putting the structure through reverse strains, then rolling from

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side to side, receiving heavy blows from waves, and subject to the vibration of the variedly immersed propeller, subjecting the vessel to a complexity of strains unknown to other structures. The calculations of Mr. William John (who deals with steam vessels built at a more recent date than Mr. Mansell) show that a first-class iron vessel of 3,000 tons is only one-fifth as strong as an iron vessel of 100 tons, and has only half the strength of one of 700 tons, supposing each to have the same relative proportions of length, breadth, and depth; and this obtains when good material and workmanship are employed, capable of bearing tensile strains on the upper works to 20 tons per square inch—a result not always to be obtained in practice. Having now laid before you a few facts which show there is room for improvement in the general structure of iron ships, especially those of the largest classes, I now ask you to consider what I believe will remedy some at least of these defects.

As regards the safety of the vessel, in the possible event of the hull being pierced from collision or other causes, or large masses of water finding their way into the interior (say through a broken engine-room skylight), the first object to be attained will be to render the effect of the damage as local as possible; which can be managed by properly spacing the athwartship water-tight bulkheads, say by dividing the main and after-holds each into two parts; by separating the engine, boiler, and coal spaces by water-tight bulkheads, and by closing all necessary openings by efficient water-tight doors capable of being readily closed. The capacity of the various compartments can be readily calculated and spaced so that the vessel may become practically unsinkable, provided the structure is strong enough to withstand the shock of the surging and pent-up water; but this would often appear improbable from the foregoing remarks. As regards the general strengthening of the whole structure, we believe nothing will tend to effect this so thoroughly as by adopting the longitudinal bulkhead system, and which has been advocated of late years notably by Captain Charles Chapman, Mr. William Denny, and Mr. John McMillan, of Dumbarton, as also by Mr. Boolds and others. It is being adopted by Her Majesty's Government, and forms a marked feature in the construction of the *Irrawaddy* flotilla steamer, built by Messrs. Denny Brothers, of Dumbarton. I am aware that this system has been long since partially carried out, as in the Cunard steamers *Persia* and *Scotia;* but I advocate its use not *locally*, as in coal-bunker bulkheads, or as a means for reducing the size of a water-tight compartment, or for forming short wing water-tight galleries, but as an essential element in the *strength* and *safety* of the *whole* vessel; as the longitudinal bulkhead extends from a deck well above the water-line down to the keel, and being made water-tight, and of considerable lateral strength, practically divides the vessel into a port and starboard ship in every particular. In advocating the adoption of the

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longitudinal system let me state what I believe to be the action and effect of the longitudinal strains of tension and compression on a flush-deck vessel of the usual construction, considering the hull as a variedly-loaded beam, the topsides, stringers, and iron deck forming the top flange; the bottom plating, &c., the lower flange; the side and part of bilge plating being the connecting link.

First, in still water the internal weights, when equally distributed and of equal gravity, have a tendency to keep the vessel's bottom down, and pretty evenly to counteract the pressure of water due to the form and immersion of the hull. But as steam vessels are necessarily loaded unevenly on account of the varying weights of machinery, cargo and coal, and more especially the latter as it is worked out during a long voyage, consequently the proportional strains along the whole length of the vessel or beam vary considerably. The ends of the vessel having a tendency to fall off, cause the lower plating to remain in compression and the upper works in tension. This consideration leads to the conclusion that the bottom is not only the lower flange of a girder, which prevents the middle from rising on account of an excess of buoying power, but also as a series of pillars resisting the tendency of the ends to come together from a want of buoyancy. As I have just said, the bottom represents a series of continuous short pillars, the length of each being equal to the clear space between the frames, the width being the distance between the bilges; and the keel and keelsons, which are connected to the plating, are the webs; and for thickness we have that of the shell itself.

Now pillars 21 inches long by $\frac{13}{16}$ inch thick, with stiffening webs say 10 feet apart, are scarcely what an engineer would recommend for resisting heavy and varying strains, especially when they are subject to a continuous one-sided thrust, as by the upward pressure of the water, which places them at a great disadvantage to resist compression, and tends to buckle or double up the pillars or shell plating between the frames. This threatened collapse is prevented by the webs or longitudinal elements of construction, *viz.*, by the keel and intercostal keelsons, assisted by the convexity of the bottom, each sharing the thrust and keeping the plating fair. The course of the strains in the variously-loaded steamer will, I apprehend, be as follows:—The tendency of the superior buoyancy over the weights amidships will be to force the bottom upwards, and to square and thrust out the bilges. To effect this the strains follow two courses—first, the floors would tend to rise and communicate the pressure by the pillars to the beams, stringers, iron deck, and ship's side; and secondly, the stress would reach the topsides and stringers, &c., through the bilge plating and bulkheads. In a few words, the floors would tend to rise and the bilges to bend before the strain due to the weights, hull, machinery, coal and cargo, could be equally distributed.

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Now the floors are prevented rising in the centre by the keelsons, bulkheads, pillars, and the cargo and other weights resting on them, also by the resistance they offer as girders: of these resisting elements I alone question the efficacy of the pillars, and for the following reasons:—It is well known that they are frequently bent by cargo or other strains, they are not continued through the engine-room, only occasionally through the boiler space, and their continuity is much interfered with at all large hatchways, consequently they cannot be relied on as an efficient means for tying the ship together; in fact I believe they simply serve to shore up the decks and only nominally act as tie-rods, so that I consider there is but little dependence to be placed on them as an efficient means of connecting the varying strains of the lower and upper parts of the vessel, and in the engine and boiler spaces of communicating strains from the iron deck downwards. The result is that the deck beams where unsupported by pillars tend to flatten when strains come on them, and the deck plating as it approaches more nearly the centre line yields with the beams, and so is not bearing its share of stress with the topsides and stringers nearest the sides; and I conclude that the strains are mostly communicated from bottom to top, or *vice versa* through the bilge plating, frames and bulkheads. Whether the curved form of the bilge is that most suited for transmitting upward strains is open to question, on account of the tendency to spring and work at those parts.

Secondly, when the vessel is traversing ocean waves equal to her own length she is continually subject to reverse strains, the bottom being often in tension and the topsides in compression, as the parts are variously buoyed, when she mounts, is poised, or descends the waves. It is not my intention to dispute that first-class vessels, as now constructed, are not strong enough to hold together when uninjured, but that I believe much material might be saved if arranged to more directly transmit the longitudinal and vertical strains continually operating between the ends and the top and bottom works of a vessel, by so arranging the material that these strains may be communicated in the most direct manner to the parts which are specially adapted to bear them, and so prevent leaky decks, working butts, and panting ends. To meet these requirements I believe nothing is so suitable as the longitudinal bulkhead or girder system, combined with additional athwartship bulkheads, some of which should be carried up to the deck which carries the top flange or girder; also by the addition of longitudinal angle irons spaced between the keelsons and connected to the plating, or by extra intercostal keelsons.

A design for constructing a vessel on this principle, and illustrating the joint scheme of Captain Charles Chapman and myself is given in Plate XXI., by reference to which the following remarks may be more clearly followed. It represents a main-deck steamer, 380 feet long by 43 feet beam by 32 feet 3 inches extreme depth

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amidships, having a gross register tonnage of about 4,000 tons; is fitted with twin-screw engines; has top-gallant forecastle for crew, and large hurricane house for first-class passengers and officers, and main deck for second-class, steerage, or cargo. The hatches are at the sides, leaving a passage next the bulwarks about 5 feet 6 inches wide, and allowing a midship belt of the iron deck at least 8 feet wide to run fore and aft in one uninterrupted length. It will be observed that the longitudinal and thwartship bulkheads divide the vessel into safe and handy compartments, each reaching from the main or upper deck to floors. The athwartship bulkheads are supported in their middle by the longitudinal bulkhead, which you will see in the second deck plan, extending from peak to peak in one unbroken length; but it may if necessary be continued to the stem and stern-post. This feature of construction adds very materially to the strength of the athwartship bulkheads, where there is no deck to stay them. The longitudinal bulkhead divides the engine boiler and coal spaces, so that if one set of propelling gear becomes disabled by water the action of the other may remain unaffected. The engine rooms are separated from the stoke-holes by water-tight bulkheads with doors, and for convenience an opening is made between the port and starboard engine rooms which is also closed by a water-tight door. This is the only opening below the second deck in the fore-and-aft bulkhead with the exception of the usual small sluice valves. The forward bunker is also rendered water-tight. I prefer to close these five doors by hydraulic power.

As all the hatchways are on either side the centre part, the iron upper deck for a width of about 8 feet forms a perfectly unbroken web or flange, which being united by vertical plates and angle iron to the ship's bottom, saddle plates on floors, and centre tie plates of the other decks, collectively form an immensely strong girder, being in fact a backbone extending from the top to the bottom, and from end to end, from which the frames and floors, beams and bulkheads, run as ribs to the outer plating, rendering to each other mutual support, so tying the vessel together vertically, diagonally and laterally, that the strains operating at one part are diffused throughout the whole structure. And this valuable feature applies in a special degree to the varying strains a vessel is subject to when at sea, especially when pitching or scending heavily, when the buoying or upholding of the individual parts is continually changing while the weights carried remain practically constant. Hence the value of the direct diffusive power of the structure under consideration, which so transmits the strain that the fully-buoyed but lightly-laden parts directly support those which for the time being are subject to reverse conditions.

As the longitudinal bulkhead means the introduction of weight where only about one-third is usually placed, let me state in a few words where I consider reductions

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may be made in the present system of construction to meet this additional two-thirds, amounting to about 75 tons. Considering that the longitudinal bulkhead forms a rigid girder, shallower floors may be used, as they cannot rise unless the girder is broken, or decks lifted and athwartship bulkheads torn. Beams may be reduced in depth, as they rest on and are connected to the girder by angle-iron collars, so cannot give way in the centre of their length unless the girder gives way or the vessel's bottom is ruptured. They are therefore practically reduced in length by one-half, and in depth by about $\frac{1}{4}$ inch. As much of the heavy strain will now pass from the bottom directly upwards by the girder to the iron decks and bulkheads, the strain at the bilges will be much reduced, and also the liability to work at these parts; hence doubling strakes at the bilges of long vessels will be unnecessary, but I would recommend that a keelson united to the skin be placed here for stiffening the shell when under compression, as the vessel lays over. The strength of the iron deck is also more effectively utilised, as it is directly in communication with the lower parts of the vessel, and in the line of greatest strain is unbroken. As the plating between the bilges and sheer and whale strakes will be subject to less stress, it may also be reduced, especially as additional strength will be got out of the side plating when laying over by the adoption of more numerous athwartship bulkheads, and by carrying them to the upper deck. The bottom plating may be also reduced when the stiffening angle irons before referred to are added to prevent buckling.

By the reduction in the depth of the floors and beams more space will be afforded for cargo; and, if it should consist of grain, it will be kept from shifting by the web of the girder—a matter of no small importance. It may be objected that the longitudinal bulkhead and twin-screw engines will much interfere with the storage of cargo; but this it is believed is more apparent than real, as the pillars displace cargo to the extent of their own thickness, and the girder with its stiffeners take up but little more, say an inch in the width of the ship. The two tunnels necessary for twin-screw propulsion occupy the wings of the after-hold and as the tanks can be placed in the space left vacant between them and the ship's side, and the cocks and pipes led through the tunnels,—ceilings, casings and trunk-ways will be saved and a good flat floor will be formed for the cargo to rest upon, both over the tunnels and between them. Besides as smaller screws will be used the tunnels will not be so high, neither will they be so long as is usual with the single-screw propeller.

By arranging the engines as shown in the plan they will take up less fore-and-aft room, saving about 8 feet in 600 horse-power engines, and this space will be in the best parts of the vessel. As the side bunkers will however be done away with, part of this space will be thrown into the midship bunker; the remainder increasing the cargo

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space. There is also another gain from using twin screws, which is that the length of the screw aperture—amounting to nearly 9 feet in large vessels—may be added to the midship length of the vessel under the water, the lines below having the same run aft, but requiring a little fining above. By adapting the longitudinal bulkhead in vessels where an entire main deck is required for passengers, and large cargo space is not of so much moment, I should recommend a spar-deck class of vessels, and carry the girder to the main deck, and every other athwartship bulkhead to the spar deck; but for the largest class of vessels I should prefer to construct them as shown in the plans, *viz.*, with top-gallant forecastle and large hurricane house. In this type of vessel I should not insist on making the longitudinal bulkhead water-tight above the second deck, provided the deck was well above the deep-load line, when I should cut openings under the upper deck for through ventilation.

In order that the advantages of the design under consideration may be more easily comprehended, I have arranged a vessel 380 feet by 42 feet by 31·3, and compared it with a very successful flush spar-deck type of steamer, of the same length and breadth but 4 feet 9 inches deeper, having the same lines and gross register tonnage; all the other elements except cargo have been reduced to the same level. The result is a gain in the cargo space of 780 tons at 50 cubic feet per ton. This gain is made up by the decreased length of engine room, extra midship length due to having no screw apertures, and also to the saving in the register tonnage by having open passages around the hurricane-house cabins, and clear spaces over the hatchways. As regards the working of cargo in vessels having side hatches, I should prefer to use a light winch for each, with a good derrick swing off the mast. This arrangement will be very advantageous where cargo can be worked both sides, or from the jetty and barge, or when landing in small packages or chests; but where this cannot be done the greater sweep of derrick to the outer hatch will neutralise any advantage which will be gained when working the nearer hatch; so that the employment of double hatches will not practically expedite the working of cargo under ordinary circumstances, neither is it believed they will prove a hindrance.

Before concluding, I would draw your attention to what I believe to be special advantages in the employment of twin-screw engines, especially as sundry objections to their use, and to the longitudinal bulkhead as a consequence, may have presented themselves to the minds of any practical men I am addressing. A very important element is that they afford greater immunity from detention through accident to machinery when on long ocean voyages, as in the event of the loss of a screw, a broken shaft, or other serious derangement of machinery, the voyage may be continued at about eight-tenths of the ordinary speed and without increasing the indicated horse-

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power of the remaining engine more than one-fifth. It is on reliable record that when the twin-screw steam ship *Mary* lost one of her propellers at sea in 1868 she completed her voyage without difficulty with one engine; it being only necessary to angle the rudder about five degrees to correct the one-sided thrust of the remaining propeller. She steamed up the Thames with ease, turning the sharpest bends, although her length between perpendiculars was 230 feet. As another instance it may be mentioned that both engines of the twin-screw steam ship *Ruahine* broke down when coming home from the West Indies; one engine was made good by borrowing from the other, and the voyage continued at 7 knots. Now compare these facts with the results of the steam ship *Atrato*, and many other cases of detention of mail steamers from accidents when at sea; and estimate the value of the time lost in a foreign port while waiting for duplicate parts, also the cost of dispatching other steamers at short notice to carry on the mails, and expenses and annoyances connected with transhipment of passengers and cargo, and I have no hesitation in saying that the balance will show largely to the advantage of the vessel with the longitudinal bulkhead and twin-screw engines; and this applies also to ordinary merchant steamers, though in a less degree. Another advantage is that the screw-propellers are more deeply immersed, and the feeding water besides being less broken and more free from air has greater freedom of access to them. There will be less vibration of the hull, as the water leaving the screw acts equally on both sides of the vessel; and when light and pitching heavily the engines will be less liable to race and the shafts to fracture from sudden and unequal strains. Referring to the value of deep immersion of screws as a great accessory to efficiency, I would remind you of the Paper read before this Institution in 1874 by Professor Osborne Reynolds, recording the results of a series of experiments, the summary of which is to the effect that screws should be one-third of their diameter under water; if less than this they race and froth the water; and this result was invariably obtained even at speeds varying as much as 50 per cent.

The action of the rudder will not be affected when under weigh, and if it should get damaged the vessel can be manœuvred by the screws alone. This special feature of twin-screw propulsion commends itself especially for canal or river work, where low speeds and great nicety of steering are so necessary. When laying to from stress of weather the twin screws can keep the vessel's head up, even when she makes no progress, being independent of the rudder; but unless the single-screwed steamer is making headway, the rudder fails to act and her head will fall off. Hence, either her screw must be turned more rapidly or sail be set. If the former the engines will be more affected by racing.

Duplicate engines in vessels of large size and full power also offer advantages on account of the individual parts being little more than half the weight, and the shafts are

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more likely to be free from flaws; besides only about half the usual weight of spare gear will be carried, and that will be of much handier proportions. As regards the cost and weights of duplicate engines, say each of 250 horse power and upwards, and with one set of spare gear, as compared to single-screw engines equal to their collective power and also with one set of spare gear, I have it from a firm of first-class marine engineers that there will be no difference between them in these respects.

A twin-screw vessel has also unusual facilities for avoiding collision; and if injured, and constructed on the principles advocated, will be able to assist either herself or the participator in the collision. Also, in event of war, she could render valuable assistance on account of extraordinary manœuvring powers, and in the event of one set of machinery being injured has the other to fall back upon.

Owing to the twin-screw system affording greater immunity from accident and increased facilities in steering, rigging may be almost dispensed with in fast ocean steamers, thereby adding to the vessel's stability and saving expense in this department.

In conclusion, I may repeat that by the adoption of the twin-screw engine the cargo space is increased, as previously noted, by 196 tons at 50 feet, which at 40*s.* per ton—and the vessel making four round voyages to Bombay per annum—would add £3,140 to the gross yearly revenue, and much more than compensate for the cost of any additional engine staff. Also by the application of the longitudinal bulkhead system combined with the additional athwartship bulkheads, the vessel is not only much increased in strength but is also rendered practically unsinkable, which together with the greater security afforded by twin-screw engines will reduce the sea risks, and so lower the insurance premiums; consequently the shipowner can command higher freights without increasing the cost of transit to the shipper, and such vessels would undoubtedly be more largely patronised by passengers as soon as the general features of security became known to the public.

And by the adoption of the general arrangement proposed by Captain Charles Chapman and myself for large ocean steamers of the size and capacity already noted, the additional 780 tons of cargo space, if freighted as above, would add about £12,400 to the gross annual revenue.

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ON A SMALL COMPOUND STEAM ENGINE.*

By Thomas Moy, Esq., Associate.

[Read at the Seventeenth Session of the Institution of Naval Architects, 8th April, 1876; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

The engine which I am about to describe is an improved arrangement of that which was brought under your notice two years ago. My first idea was to form the cylinders and reservoir in one casting, adding a steam dome of suitable dimensions, and mounting the whole upon a suitable frame, with two tube plates, generating tubes, and furnaces.

Messrs. Dudgeon entered into a contract to construct a compound engine upon this principle, and when a considerable sum of money and much time had been spent upon it, it was found that the casting, which was a heavy one, was unsound in two places; much delay thereupon took place, and that engine was for various reasons abandoned. Another design was prepared and the plans approved of, in order that Messrs. Dudgeon might carry out their contract; but funds running short with me, and Messrs. Dudgeon soon after closing their works, the engine has never been completed.

From the experience gained in the several experimental engines that I have had constructed, I have been able to so modify the several parts that all difficulties in construction are entirely eliminated, and engines of any size and power can be produced with facility.

In the engine before you the cylinders and valve-box are cast in one with the base plate which forms the bottom of the water and steam reservoir. The cylinders, &c., are bored truly, and the top covers inserted. The base plate is faced up, and the steam and water dome is bolted down upon it, the tube-plate fitted with tubes is bolted to the side of the dome.

By this, which appears at first sight but a slight alteration in the arrangement, all the parts can be cheaply made, the work being nearly all lathe work, and for economy in weight, space, first cost, and working it is difficult to see where there is much room for improvement.

* Received 14th March, 1876.

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This engine is worked at from 120 pounds to 200 pounds to the square inch, and as excellence of workmanship combined with cheapness and simplicity are aimed at, the valve motion is of a very simple construction. A semi-circular main valve with a stroke of only half an inch, and a semi-circular cut-off valve with a stroke of $\frac{3}{4}$ of an inch, effect together the distribution of the steam, which is cut off at one-third of the stroke in the high-pressure cylinder, and by the action of the main valve passes direct from the high to the low-pressure cylinder, and as the cylinders are in area as one to three the steam is expanded nine times.

The tubes are made of solid drawn metal for internal pressure, the substance being sufficiently thin to allow of the rapid passage of the heat to the water, and yet of sufficient strength to allow of an ample margin of safety; and each tube is tested to half a ton to the square inch. The very rapid circulation of the water which takes place in the tubes is a perfect preventative to burning the metal, and as a matter of practice they seem to be imperishable; and, as was well pointed out by Mr. Charles Wye Williams more than twenty years ago, the rapid circulation of the water is the best thing for rapid production of steam. I have also found in practice that by placing the tubes very near together little heat can escape, the tubes being kept comparatively cool by the circulating water, and absorbing the heat as a dry sponge absorbs water.

A tube plate is on the table which has had some months' work, and which shows that there is no amount of deposit taking place in the tubes beyond a very thin scale.

The arrangement now brought under your notice is intended to utilize common gas as the fuel; and for this purpose I use Wallace's gas burners, which burn entirely without smoke. But the furnace can be arranged for any other fuel. The first heat goes of course to the steam-generating tubes. I am arranging a peculiar form of feed apparatus which will utilize the surrounding heat outside the steam-generating tubes. Surrounding this feed apparatus I have a cylinder of non-conducting material, and outside this a cistern containing the feed water: so that the products of combustion are pretty well utilized.

As I am just now conducting experiments with this feed apparatus, I would rather reserve my remarks upon it to a future time. In the meantime the engine can be worked with an ordinary feed pump or injector, and there is no difficulty whatever in preserving the water level.

In conclusion I think I may say that I have invented a steam engine which for simplicity, economy, safety and lightness, will stand comparison with any engine that has yet been produced, and for facility of transport will compete with any other engine and boiler in existence.

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DISCUSSION.

Mr. HENRY LIGGINS: My Lord and Gentlemen, I should like to make one remark only in reference to this particular steam engine standing before me. It appears to me to have been constructed for the use of a steam launch. I would ask the inventor whether I am right in saying so?

Mr. MOY: No; I should make a lighter one for a steam launch. That is a stationary engine of what I call my heaviest class.

Mr. LIGGINS: I am merely objecting to the form of it for a steam launch. We always try in steam launches to get the weight of the boiler as low as possible, that is to say, a horizontal boiler is preferred to a perpendicular one. With regard to steam-generating powers, I should think it is a very rapid one, but that is a matter of experience and not perhaps of private opinion. It seems a very elegant little apparatus, and extremely suitable for a steam launch, if you can place the boiler horizontal instead of perpendicular.

Admiral J. H. SELWYN: I spoke last night on Mr. Flannery's Paper, with reference to the enormous advantages to be gained from tubulous boilers, as compared with the existing type in the service which we call tubular. Here is a specimen of what can be done by the rapid circulation of water. Whereas now for boilers we carry an enormous weight of water, and evaporate slowly and inefficiently; this system permitting, as it does, of a rapid circulation of water through the tubes, which may be arranged vertically instead of horizontally, or in any other shape; yet if there be a rapid circulation of water you do not need to carry more water in the boiler, and therefore you do not need to expend more heat in heating that water, which you only bring out again when the boiler is cooled down, than is absolutely necessary for evaporation per pound of fuel per hour for work to be done. That is one of the great advantages of tubulous boilers. The advantage of the application of fuel also is a very large one, since the sides of the furnace may be coated with any material like fire-brick, and thereby more perfect combustion will be obtained; whereas in our present boilers we can do nothing of the kind without sacrificing largely the heating surface of the boiler. The time also in which the steam is got up in all boilers constructed on the tubulous system is an important element of success for naval purposes, since, as we shall rarely go about under full steam, and may very suddenly be called upon after a foggy day or a dark night to employ our full power, it is essential to the efficiency of the ship that she should be able to get her steam to a full pressure in the shortest time. This can never be done if large bodies of water are to be heated. If we have got by tubular boilers to something like three-quarters of an hour for raising steam instead of an hour and a half or two hours as used to be the case before tubular boilers came into use, that is a large measure of improvement, but it is nothing in any way approaching to the improvement which is promised by this system. The tubulous system offers the advantage (I am not speaking now with reference to any particular model which is before us, because there will be naturally modifications which no doubt the author of this Paper would import into it, if he were asked to provide for salt water and its encrustations, as well as for the ordinary work of a small steam engine) that you can carry all your weights very low down. I think it is not quite understood that here the weight of water is not that of the old system of boiler, and consequently the objections do not obtain to the placing of the boiler as it is here. The principal weight I take it in the old system is of the reservoir of water,

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not of the engine below it. The advantages also to be gained by carrying very high pressures, which I think still, in spite of all that has been stated, will make themselves more and more strongly felt, as we study more and more the economy of heat, can best be obtained under a tubulous system, because no large, unstayed, ill-shaped surfaces will be necessary, and whatever pressure is to be given to that reservoir, as it is called, may be carried in a properly-strengthened structure, the tubes themselves being perfectly safe at the enormous pressures spoken of by the author of the Paper simply on account of their very small size. We all know that the available strength of metal increases very largely in proportion as you diminish the size of the structure into which you put it; and here the thicknesses, though quite small enough to allow of the proper transmission of heat, are quite strong enough to resist all the pressure likely to be applied to them.

Mr. Moy: In answer to Mr. Liggins, I beg to say that we fitted a boat 25 feet long, 5 feet beam, and 2 feet deep—not a very large boat—with an engine, but our engine was so small that it seemed almost lost in the boat; it only weighed 1 cwt. and a quarter. It was taken down by train, put on board the boat, and the screw fitted and tried at a measured mile. She went six miles an hour, going with and against the tide. That boat really could carry three times the power comfortably, and still the centre of gravity would not be much raised. I could manage so that the centre of gravity could be very low indeed.

Admiral Selwyn: Would you state what power that engine was?

Mr. Moy: Three-horse power. Admiral Selwyn has referred to several matters, in which I quite agree with him. That rapid circulation of the water is the correct thing, and we have it really perfect here. This circulation is very rapid indeed. If you take a metal rod and put it to those tubes while the water is boiling, you can hear the rapid circulation taking place; the upper tube delivers the steam and water in all cases, and the lower tube takes the ingoing water, so that there is a steady circulation going on. I should have explained to you with regard to my expansion valve, that it is rather different to the common expansion valve. Here is the main valve, and I prefer having the lip of the expansion valve exactly covering the two ports, and I have only to alter the angle of advance to what I like, and I can cut off at any part of my stroke. In this case my angle of advance beyond the main valve is 60 degrees, and so I cut off at exactly one-third of the stroke, and it effects a very sharp cut off, which is a great advantage in expansive engines. I am much obliged to the gentlemen who have so patiently listened to me.

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ON BOATS' DAVITS.*

By R. A. Allardyce, Esq.

[Read at the Seventeenth Session of the Institution of Naval Architects, 8th April, 1876; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

Before describing a new form of boats' davits, I will make a few remarks concerning the way in which boats are now carried on board the numerous large passenger steamers, not only crossing the Atlantic, but also in the majority proceeding to other quarters of the globe, as well as the home-trade passenger and other coasting steamers. They do not hang externally from the davits, but are swung inboard, the larger ones are lowered on chocks, and carefully covered up with canvas. No doubt this is a very good way of preserving the boat, but it puts her at a great disadvantage in case of an emergency.

I have no doubt that many passengers travelling by any of these steamers will have wondered how, in case of an accident endangering the safety of the ship, *these boats can be got overboard in time to be of any service*, through the way they are now carried, housed, landed on deck, and covered up inboard. Oft-repeated cases of shipwreck, fire or collision, only too painfully testify to the great loss of life arising from the impossibility of launching the boats from the chocks, resting on which they are so carefully covered up.

They would not be carried in this position at sea unless there was a very good reason for it, and that is well known to any sailor. If not carried inboard they are washed away from the davits, and sometimes the davits with them by the heavy rolling of the ship in a sea-way. So, to guard against that danger, they are swung inboard in the manner I have described. With the present shape or form of davits the sailor has no alternative. If he carries them outboard, the chance arises of their being swept away. So he prefers the least of the two evils, carrying them inboard, trusting to circumstances in getting them out in case of accident, generally attended with failure.

As a sailor, I look upon it as impossible for a boat, crowded with panic-stricken

* Received 4th April, 1876.

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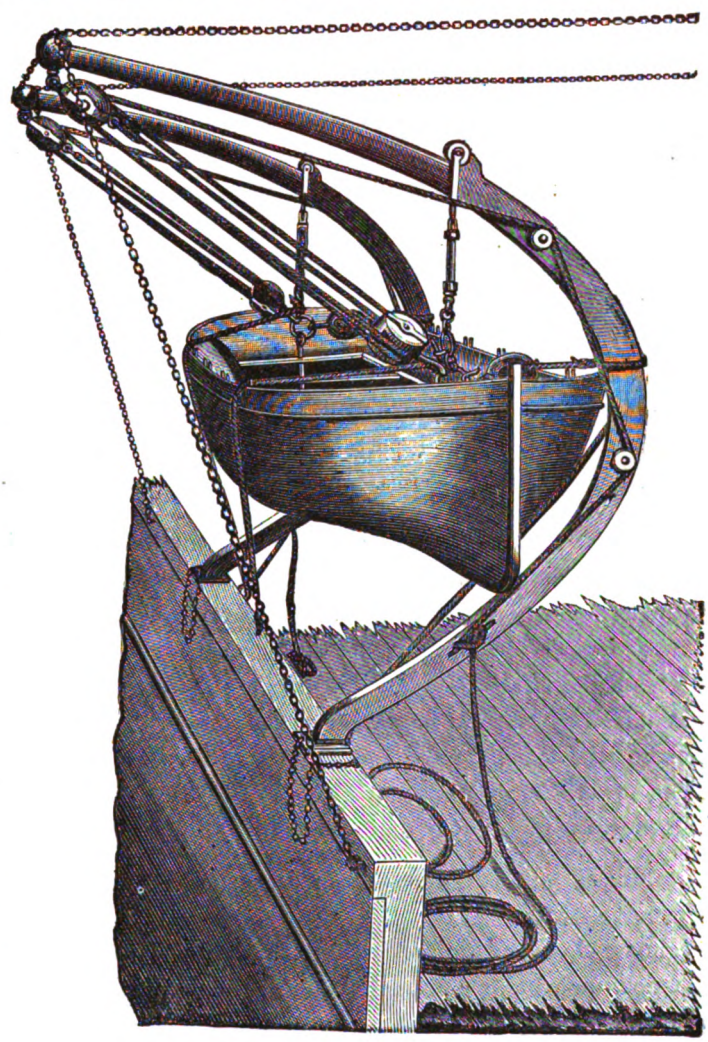
passengers, to be pulled up from the chocks, and swung out ready for lowering from a sinking ship in anything like reasonable time; and I think any one who has had the misfortune to witness such a scene will agree with me.



To prevent this great evil, I have, with the assistance of Mr. Graham, late of the Peninsular and Oriental Steam Navigation Company, constructed davits for ships and steamers, from which when at sea the boat hangs inboard, as she would from an ordinary pair of davits swung in, and at the same time *ready for being instantly swung out and lowered*, the weight of the boat taking her to the perpendicular.

These davits are curved inboard sufficiently to allow the entire breadth of the boat to hang inside a perpendicular line from the ship's rail, where she will be as secure from the action of the waves as from a pair of ordinary davits swung inboard, with the boat lashed down on chocks. By slacking off the guys she is ready for lowering, and as she may be fitted with any of the approved methods of disengaging gear (a subject I am not at present advocating) she will at once be free on touching the water. In getting the boat into this position, and to avoid the cross strain that there would be in rousing her in, we have fitted stoppers with rollers on the davits, which are hooked on after the boat is hoisted close up; the tackles then being slacked the boat lowers into the position in the bend of the davit I have before described.

By this plan we hope boats will be ready for lowering in two or three minutes, and instead of the old story, "*unable to launch the boats*," they will in cases of accident be promptly lowered, and many lives saved which otherwise would have been lost.

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DISCUSSION.

Mr. BENJAMIN MARTELL: I think a word or two may be said on Mr. Allardyce's Paper, from a nautical point of view. There is no doubt that improvement could be made in boats' davits, more particularly for passenger ships, when we so frequently hear of instances of the ineffectual attempts to launch them in times of danger. It is a matter of considerable importance, and no doubt great improvement is to be made over the system we adopt at present. At the same time, as regards Mr. Allardyce's plan, from what I see there I imagine the davits would be of immense size and weight to do their work. Their distance inside the ship would be something very considerable indeed; and although there would be no practical difficulty in making the forgings—when we see the davits at present used, sometimes large davits of 6 inches in diameter with very little curve to them comparatively twisted and strained to the extent they are—I fear that davits with such an enormous curve as that, and where the weight of the boat almost comes on the horizontal part of them, would require a great deal of consideration before they were adopted for general purposes.

Mr. CHARLES LAMPORT: I wish to point out, my Lord, that one great advantage of this system is, that the chief weight is kept well inboard. Instead of the boat hanging at the end—which would be a fatal objection—its weight is brought as well in and is nearly over the centre of the curve, and there is very little strain as it seems to me on the davit. In fact, in the ordinary davit, where the weight is always hanging at the greatest disadvantage to the support, a much larger and heavier weight of forging is required than would be actually necessary in this case, where the weight hangs so far inboard during most of the time. Of course the weight would be extreme just at the moment when the boat was being lowered or raised, but that would be only for a very short time. It strikes me that the plan is a most ingenious and admirable one.

Mr. HENRY LIGGINS: From the experience I have had, which is considerable, in large passenger steamers—not only in the Peninsular and Oriental, but the Cunard, the Royal Mail, and other West Indian steamers—in every kind of weather, and having noticed particularly the process of boat lowering, under the most unfavourable circumstances, I should like to point out what appear to me to be some very strong objections to this plan. I quite agree with Mr. Martell that this form of davit would involve a great deal of extra strength and weight of iron. That is an objection. Another is, that, as a fine-weather passenger, travelling from the West Indies, I should very much object, during the whole of a long voyage of three weeks, to have those boats and those davits constantly over my head in promenading up and down the deck, with 300 passengers to occupy that deck. I think they would be thoroughly out of place, because they would be in the way. If they were the ordinary form of davit—indeed, almost in any weather that prevails in the Atlantic—those boats would be outboard; and it is a rare thing for them to be carried away, for this simple reason, that with the present form of davit—which we saw on the *Faraday* model which was here yesterday—in less time than I take to speak on the subject it is quite easy to reverse the davits and swing them inboard, and to do it quite as quickly as this boat could be launched from her present position; the davits swing in and out, and two men can do it—one at each davit; she can be launched in a very short space of time indeed; and therefore that objection is easily removed. Then it is said the boats are generally covered up with canvas. I should like to know, under

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a tropical sun—and the sun is tropical between Southampton and New York in the summer time—what boats would be like, when they are required for use, if they were not covered up with canvas to prevent their seams opening? I have seen boats leak like a colander when they were lowered into the water, although they were covered up with canvas to keep the greatest power of the sun off. Another objection to this is, that it requires great care—more care than it would get under the adverse circumstances of being required to be lowered hurriedly to save life. That boat clearly, without there was a man at each davit, with carefully arranged guys, would swing out with a great swing, and probably the guy might break if she were full of frightened passengers; then, again, while being lowered she would swing back with a very great swing, and probably smash her gunwale. That I look upon as a perfectly fatal objection to this plan. I should be sorry to trust my life to a boat so arranged; and from the experience I have had in boat lowering I find that the most practical authorities still adopt the plain old-fashioned method. It was my good fortune, in the month of March, some years ago, to spend a particularly pleasant week with the Trinity Masters, in one of their beautiful yachts. We had such an exceptionally severe gale during the whole of that week that it was with the greatest difficulty we could relieve several of the light-ships in the estuary of the Thames. We tried two days running to relieve the Tongue Light-ship, the Girdler Light-ship, and the Prince's Light-ship, and we were obliged to give it up until the next day, when we did succeed. After that, with great difficulty, we relieved the Kentish Knock and the Galloper; and after that we went to the Goodwin North Sand Head Light-ship, which was in distress. The boats of that fine ship—which monthly had to do this hard service—were fitted in the most primitive manner, with davits of the plainest possible form, such as I have described as being used in the large ocean steamers. They had no Clifford's Patent Lowering Apparatus; no new-fangled patent clip-hooks for hooking on the boat; but everything was of the most simple practical kind. The falls were as simple as it was possible to arrange them. I form my opinion on what is done by practical men like the Elder Brethren of the Trinity House, who are aided by the experience of the efficient captains and sailors who man those boats. I will give you another reason why I think we should be guided in forming an opinion by such practical men. It has been my good luck to spend many weeks in the summer on board some of our finest yachts; and I have had some very severe weather indeed in some of those yachts in the English and Irish Channels. Their boats are very frequently fitted with some of the new arrangements that have been brought under our notice; but I find invariably that they never answer when they are required for use, and that the sailors who have to man them in the winter months, who are the fishermen of the North Sea, never like them. If such practised and able seamen as those who are to be found in our yachts in the summer—the finest seamen in the world—do not like these arrangements and new-fangled inventions, depend upon it the rough-and-ready crews that go on board passenger steamers, when they leave the ports of Southampton, London, and Liverpool, would be very much at sea indeed if they found in a case of emergency that they had to deal with some apparatus which was quite new to them. Therefore, as a rule, I set my face against all these new inventions; and as to this one I cannot see that it has one single point of merit to recommend it to our notice.

Admiral ALGERNON F. R. DE HORSEY: I must differ a good deal from the last speaker, for I hail with great satisfaction any improvement with regard to the lowering of boats. I think that we have not seen enough of the inventor's plan, and that he has not quite sufficiently explained to us how he does ease it off; perhaps he would be good enough to do that. In opposition to what has just been said, I look upon the davit that has to be swung out when the boat is wanted as the rudest and most

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inconvenient contrivance that can be. My experience is considerable in the matter. It is a thing that has to be done when you clear for action. Boats at the present day at sea are kept inboard in most vessels, and I can assure you, with all the advantages of hundreds of men in ships of war, it is a most inconvenient and disagreeable operation to swing out the davits. All the guys have to be let go, the thing turns round, and if it has got a twist in it there is a very good chance of its coming on your head. If I might throw out a suggestion to the inventor it is this: what we want to come to is something of this sort, but I should like to cut the davit off *here*, and to hinge it *here* [*illustrating*]. I merely throw that out as a suggestion, which the able inventor will probably think of. If he could cut his davit off *here* and hinge it on *here*, and by some simple contrivance ease it over when the boat has to be lowered, it would meet what we want in the Navy better than anything else that I have seen suggested.

Mr. E. C. Warren: I think great praise is due to Mr. Allardyce for his very ingenious suggestion. I think anything that gives rise to a discussion connected with boats' davits and the raising or lowering of boats must be interesting to all those who have to do with ships. There are certain difficulties in the way which I should like to speak about. According to this arrangement I apprehend there would be about 22 feet overhang for a large boat. You need not have them solid, because we make davits in different ways now. We have lately got into the habit of making tubular davits. I have made some with 13 feet 6 inches overhang out of $\frac{1}{2}$-inch ordinary plate turned to 8-inch diameter, which will take a very heavy boat with the advantage of being much lighter than solid davits. There is another form of davit that I have made; it is made simply with two T irons. You bend the T irons to your shape, and then weld them up afterwards by a process that is well known to mechanical men; and by making the inner bow of increased dimensions as compared with the other, so as to make up the difference between the compression and extension of the iron, you get the strongest form of davit with a given quantity of iron. I do not think either of these forms would remedy the great defect of having that large overhang. The last gentleman who spoke pointed out what was to my mind a very sensible thing—hinging them on the gunwale. I have had the pleasure of fitting boats' davits in that way. There are two pairs of davits fitted on board Her Majesty's ship *Raleigh* in that way at this time with a hinged joint; we turn the thing back so that it is either lowered out or brought in with very little trouble. I would point out to Mr. Liggins that it is not easy to turn boats in and out for various reasons, and he must also bear in mind that there are many positions in a ship where it is impossible to turn a boat in. The question of the rigging would be got over by this method, but I am afraid it is too heavy and too expensive and not easy to work. I think the suggestion of Admiral De Horsey would meet the difficulty, the boats would be always in position, and easily stowed inboard.

Rear-Admiral J. H. Selwyn: I am also happy to be able to offer some little crumbs of comfort from an old seaman who has lately supplemented his naval experience with a good deal of passenger work between England and New York. I can tell the author of the Paper nearly what is wanted—what we do now, and what we ought to do. I think that this is a very great improvement. I quite agree with Admiral De Horsey that there ought to be hinged davits. I quite agree also with the last speaker that there also ought to be much better-formed davits than we now have, and that the worst use you can put a piece of round iron to is to curve it, and then expect that it will keep that exact curvature under the heavy strain brought to bear upon it,—not as is supposed by lowering the boat, or by the boat when in position, but by the sudden strain and jerk of taking her out of the water. The boats on board

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the Inman line of steam ships and most others—(I have been on board of them all—the White Star, the National, the Inman, and the Cunard, although I do not believe in the latter)—are carried not only inboard, but on fixed stanchions so placed that it would be almost impossible to lift them in any useful time. The experience on board these steamers was (and that was the principal objection) that when the boats were wanted there was a disorderly rush of passengers to the boats, preventing anything being done; but if the passengers understood how these boats were to be got out, how to place themselves in them, and were perfectly aware that they could be quickly and easily lowered in them, I think a great deal of that disorder would probably vanish. There is one thing more which I think Mr. Allardyce has not paid sufficient attention to, and that is that in the pitch and roll of a ship a boat merely hung in that way by the tackles is liable to a motion fore and aft and sideways, which results in chafing and straining the boat; but with that form of davit worked on hinges, as it should be most undoubtedly, there is no difficulty in putting proper chocks on the davits to receive the boat which the circular motion of sending off from the ship's side would relieve the boat from. With those chocks, which can be made by leverage to press on the bottom and take the weight of the boat, there would be no difficulty in lashing or securing a boat so that it should not chafe. The next thing is, that in those davits with their great curvature there is the important difference that the boat is much further from the ship's side than she would otherwise be when being lowered. One of the great difficulties in lowering a boat in a rolling ship is that she is liable by the rolling of the ship to be forced suddenly against the ship's side and staved in. If you can carry the davits well in when in their ordinary place so as not to offer much obstacle, but when you are lowering a boat to be very far out, then you have an enormous advantage, and therefore I say that hinges are the right things to apply. Now as to the employment of iron at all. I would suggest whether it is not better to use steel in such a position, which certainly would give in the form of double T, already spoken of, an ample strength with less than one-third of the weight. I think that with those modifications the improvement suggested to us here is one very well worthy of being entertained, and I hope to see it succeed still better by the improvements which it may receive from our discussion.

Mr. William Poole King, F.G.S.: A great objection to the use of boats hanging on davits is that in case of the loss of a boat it is not allowed to be charged to the underwriters—that is if it is on davits on the quarter, but if it happens to be in the body of the ship then the underwriters are considered liable for the cost of it. That is one of the reasons which militate in merchant ships against carrying boats on the quarter on davits. We will suppose that objection got over. I think Mr. Lamport might mention that to the underwriters, and get that rather absurd rule altered for us. Then an objection that has been urged against this improved davit is that it has an immense overhang, and therefore would require to be of very heavy iron indeed. The mechanical force of the weight of the boat only acts upon the overhang when you are getting the boat inboard again. We can modify that by having a guy rope to the tops at the end of the davit, and then the mechanical strain would not be so great upon that point. It might not be convenient always to have a guy to the tops, for in lowering the boats there is a strain for a very short time. While the boat is between the deck and the water it would be certainly hanging upon the points, but if your guys were made from the middle point of the davit (I do not know what it is technically called) by using them and lowering at the same time, I think that we need not have the davit very strong because it is not always in use. Of course the boat would be hanging not from the extreme point but from the middle in ordinary times. There is another point which I wish to refer to, that is that the lowering ought to be always from the inside of the boat, and not as it is in that arrangement

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from the outside of the boat. I think if you put the end of a fall round one of the thwarts it might be easily lowered down by a few hands who would be inside, and could at the same time manage the guys; so that in fact it need not be so heavy and strong an affair as has been urged here. The overhang would be employed for a short time only while the boat was lowering. I consider it altogether a most useful invention.

The PRESIDENT: I recollect that at many (I was going to say at most) of our Annual Meetings we have had suggestions offered with regard to this interesting question—the best mode of carrying and launching sea-boats; and I must say I think we are always under an obligation to any gentleman who applies his ability and his experience to any improvement on a matter so important to the comfort and safety of all who travel on the sea. I must say as far as I can form an opinion I think this is no exception. I am glad to hear from my two gallant friends, Admiral Selwyn and Admiral De Horsey, that they take a favourable view on the whole of this invention. I think it must have been very gratifying to Mr. Allardyce to have heard the degree of approbation expressed, and I would venture to suggest whether it is not worth his while to consider the practical suggestions which have been thrown out by Admiral Selwyn and Admiral De Horsey for the improvement of the apparatus.

Mr. LIGGINS: Might I ask the favour of being allowed to lower the boat and show according to my views what would happen. My idea is this. Under the circumstances of saving life at sea we always find that something goes wrong with a boat. We know perfectly well there is nothing more common. I will illustrate the fact from the circumstances that occurred on the occasion of that most pitiable and lamentable of all disasters at sea, the burning of the *Amazon* some years ago, in which I lost a good many valued friends. The boat lowering is the fatal cause of nearly all these accidents. Aboard the *Amazon* the poor stewardess who was lost (a very worthy woman) was in one of the boats, the fall of which being lowered at one end before the other, it went down into the water in that way, pitching everybody out. Then there is the case of the *Schiller* at Scilly, where the boats could not be lowered although fitted in a most primitive manner, which I contend is the best for practical purposes on a dark night. Then there was only the other day the case of the *Deutschland*. I listened to every word of that trial to see if anything could be gleaned from it. There was a difficulty then in lowering the boats, some being swamped in the operation, and although it was done by Germans who are supposed to be careful and cool under the most difficult circumstances the result was the boats went entirely into the sea. Now we must suppose that in saving life there would not be the coolness there is in this room while we are trying experiments, but that the sailors would let go the ropes unevenly in lowering the boat into the water. In my opinion the probability would be that many persons would be thrown out, and that the boat would be stove in and receive considerable injury. That is the reason why I expressed the opinion I did.

Mr. WARREN: I think Mr. Liggins has lost sight of the fact that there is a possibility of marrying the falls.

Mr. LIGGINS: They are married in many cases, but there are still great objections to any apparatus of that sort. There is a special apparatus in some vessels for marrying the falls, and to some extent the risk is lessened by one man being required instead of two. The falls are married and passed over a sheave in some of the boat-lowering apparatus which is now in use, but I think that under the circumstances of hurry and confusion which are usually attendant upon the sudden lowering of a boat the plan is too complicated to be practicable.

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Admiral SELWYN: Just allow me to say to Mr. Liggins that there is a class of fools at sea whom we call lubbers, and nobody has ever yet discovered a remedy for them.

Mr. W. W. RUNDELL: Would you allow me to ask a question? My object is to ask my naval friends here what they think of the practice of hanging two boats from three davits. We have recently seen in the newspapers the particulars of an accident on our southern coast, when great delay was occasioned in getting out the boats by two boats being hung from three davits. As this was a passenger steamer, I presume the arrangement must have been made with the approval of the Board of Trade Surveyor, but I should like to know whether it would meet with the approval of our friends here?

Mr. R. A. ALLARDYCE: There was one objection raised as to the boats being covered up with canvas. I do not allude to that at all; I think it is necessary to have them covered up, but to carry them inboard on chocks is I think a very bad practice. The canvas cover is necessary to keep the sun off and the boats free of water. There are many kinds of hinged davits, but there is one thing in connection with them, that they do not hang outboard, and before you can lower a boat from any of the hinged davits that I have seen you must get the davits out by some means, either by screws, machinery, cog wheels, steam or hydraulic power. I have gone through all of them. Here I have tried to do away with that sort of thing, and to make the davit in as nearly as possible a perfect form. Instead of having to swing it out or to turn the davits out, she launches herself. The overhang is not more than is the case in the ordinary davit. In conclusion, allow me to say that I am very much obliged to Lord Hampton and you, Gentlemen, for the kind way in which you have noticed my attempt to reduce a great evil, and I tender you my sincere thanks.

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ON THE COMPOUND SURFACE CONDENSING ENGINES OF THE PADDLE STEAMER "HIRONDELLE."*

By Monsieur J. A. NORMAND, Naval Architect and Marine Engineer, Havre, France.

[Read at the Seventeenth Session of the Institution of Naval Architects, 8th April, 1876; the Right Hon. LORD HAMPTON, G.C.B., D.C.L., President, in the Chair.]

As may be seen by the accompanying engravings, these engines, which I designed and built last year, are of an entirely new type.

The small cylinder is placed above the large one, both converging towards the axis of the paddle-shaft. Each cylinder acts upon one crank, and the cranks are connected by a drag link. The irregular space between the two cylinders, which are placed obliquely to one another, serves as an intermediate reservoir. The axes of the cylinders are not situated exactly in the same vertical plane. The distance between these axes being less than that of the two crank pins, the connecting rods have a slight lateral deviation, as in Randolph and Elder's paddle engines.

The following advantages seem to belong to this new type of engines:—

1.—Lightness.

2.—Great stability of the whole mechanism, provided the box beam on which the ends of the framings rest be properly secured.

3.—Strength: there being no intermediate shaft, and the working of the engines being nearly independent of the slight strainings of the hull.

4.—Small encumbrance of the engine room.

The condenser, which is entirely independent of the cylinder, is provided with one cluster of tubes only instead of two or three as in ordinary engines. The circulation of water is effected by the speed of the vessel.

The following improvements have been introduced in the condenser:—In order to increase the quantity of water, which is generally insufficient when no mechanical

* Received 28th February, 1876.

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contrivance is used for the circulation, the tubes of the condenser are provided at both ends with a conical nozzle.

In the engine of the *Hirondelle* the packing of the tubes consists of a sheet of india-rubber, and the nozzles are very simply made by counter-sinking the holes of the compressing brass plates. By these means the velocity of the stream may be made to increase gradually at the ends of the tubes, instead of changing suddenly from 1 to 3 or 4, and *vice versâ*. As will further be seen, the arrangement has answered exceedingly well, and the quantity of water running through the condenser is proportionately much greater than is generally the case.

A simple arrangement has been provided for causing during stoppages a circulation of water sufficient to prevent the vacuum from disappearing.

A steam pipe is made to open in the after canal and in the direction of the ordinary flow of the circulating water. It has been impossible to measure the quantity of steam thus expended, but when at moorings with the engines running at full speed a small jet has been found sufficient to ensure a vacuum of 26 inches. The pipe can be made, as in the *Hirondelle*, much larger than necessary for that purpose only, so as to be available for the escape of steam when the pressure is too high—a good plan especially on board passenger steamers.

On account of the small expansion of steam (about 4 times), and in order to reduce the weight of the machinery, the cylinders are not steam-jacketed but covered with felt and wood. The steam is slightly super-heated in the smoke-box. If a greater expansion were used it would be impossible to dispense with steam jackets, especially for the low-pressure cylinder.

The following are the principal dimensions of the hull and engines of the *Hirondelle*:—

HULL.

Length at load line	144 ft. 0 in.
Breadth, extreme	19 „ 2 „
Depth from upper side of keel plate to top of beams, measured at beam's end	9 „ 7½ „
Draught of water with 19 tons coals and extra weight	4 „ 8½ „

ENGINES.

Length of stroke	37¾ in.
Diameter of high-pressure cylinder	29½ „
Diameter of low-pressure ditto	47¼ „
Admission of steam in high-pressure and low-pressure cylinders in cents. of stroke	68
Diameter of air pump (single acting)	19¾ in.
Length of stroke of ditto	15 „
Diameter of paddle-wheels at centre of rotation of floats	11 ft. 2 in.

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CONDENSER.

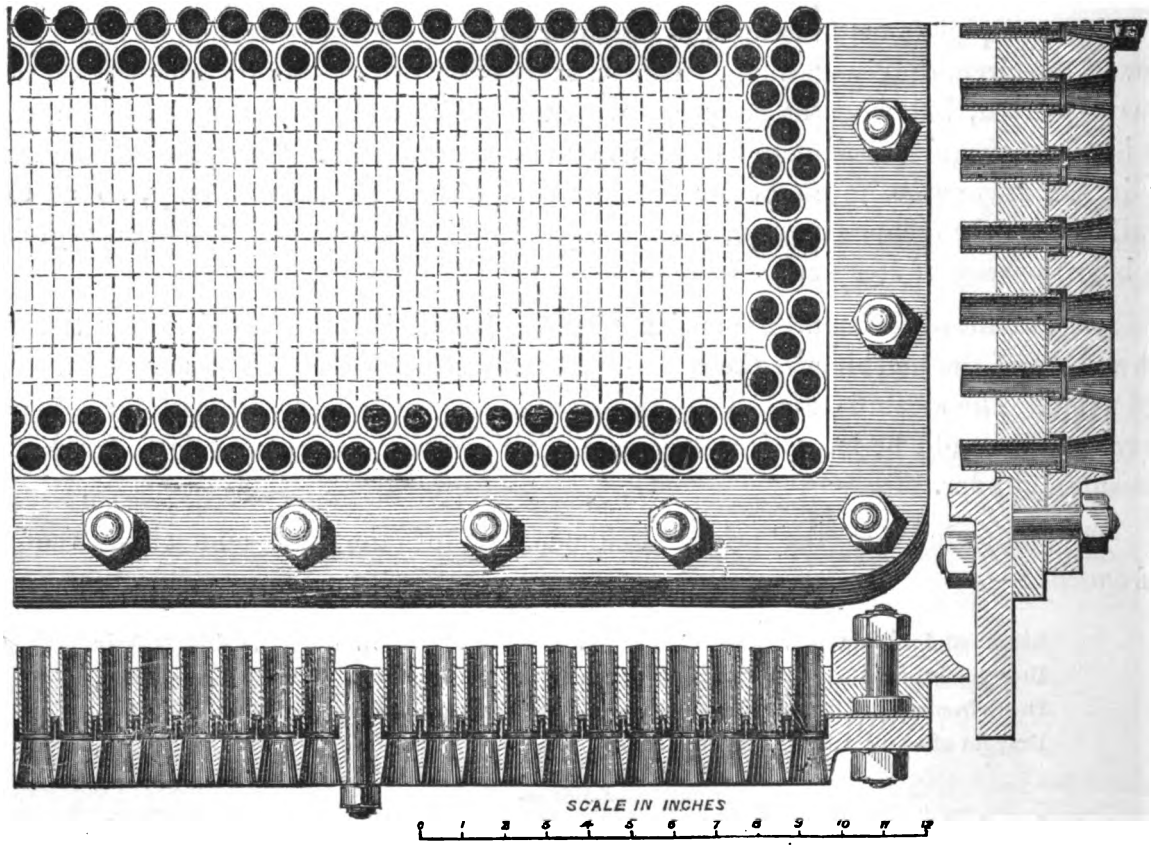
Total number of tubes	861
Internal diameter of ditto ... ... ($\frac{5}{8}$ in.)	16 millimetres.
External ditto of ditto	18 „
Length of tubes inside tube plates	5 ft. 5 in.
Total condensing surface	863 sq. ft.
Smallest section of the circulating water canal	0 sq. ft. 69

BOILER.

The boiler (single) is entirely made of mild steel.

Pressure	50 lbs.
Total heating surface	1,360 sq. ft.
Total grate ditto	46½ „

DETAILS OF CONDENSER.



The trials made in September last gave the following results:—

At full speed (13 knots, 400 horse-power and 47 revolutions) the temperature of circulating water was found to be at entrance 68°, and at exit 77° Fahrenheit, the feed varying from 95° to 100°.

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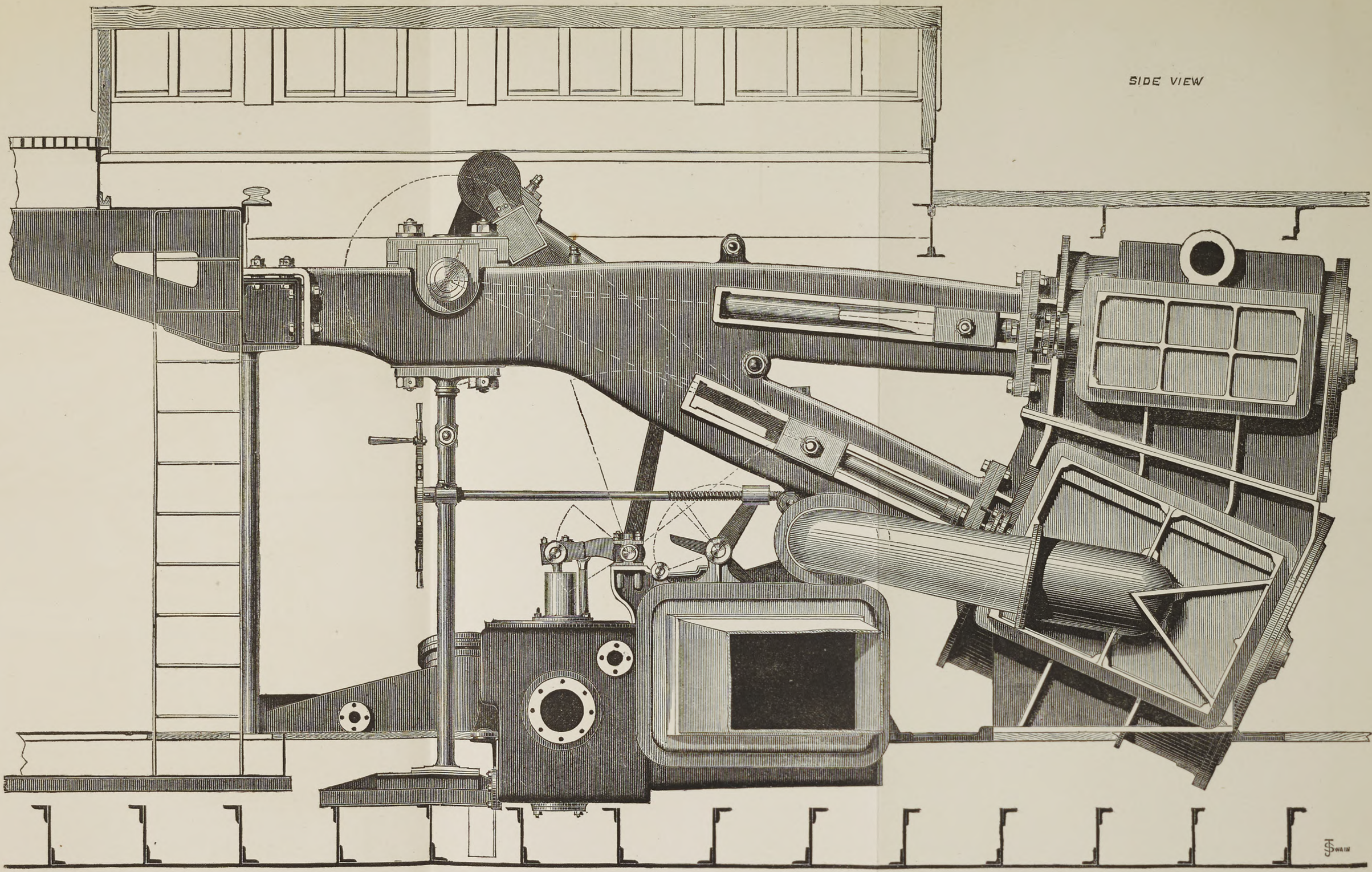
THE COMPOUND SURFACE CONDENSING ENGINES OF THE PADDLE STEAMER "HIRONDELLE."



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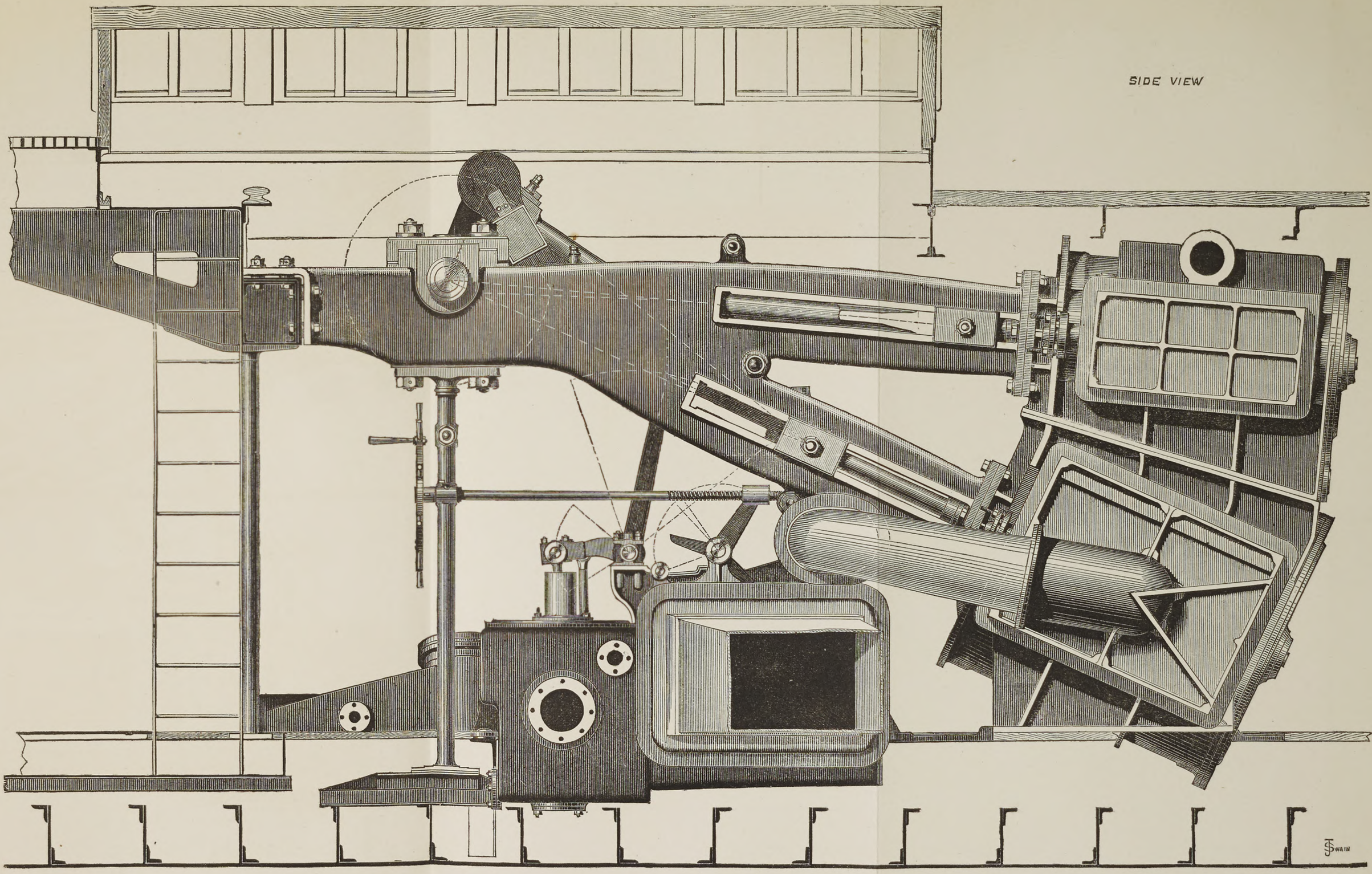
THE COMPOUND SURFACE CONDENSING ENGINES OF THE PADDLE STEAMER "HIRONDELLE."



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The vacuum in condenser was 27½ inches, the barometer being 29¾ inches.

The weight of circulating water was about 430 tons per hour, and the speed at entrance and exit from 0·28 to 0·30 that of the vessel.

At very low speed (28 revolutions) the temperature of circulating water at exit was reduced to 73°, and that of feed to 89°.

This winter the vacuum has risen from ½ inch to 1 inch.

These results seem to show that, provided good care be taken to reduce as much as possible the resistance experienced by the circulating water, the circulating pump may be dispensed with without increasing the ordinary condensing surface. I confidently expect that even at low speed with strong head wind the vacuum would be sufficient.

DISCUSSION.

Mr. J. Scott Russell, F.R.S.: My Lord, I have carefully followed the description and drawings of this very elegant construction. The inventor has got over a great many difficulties here in an extremely simple manner, and I especially call your attention to the excellent arrangements by which the whole work of the condenser is done I might almost say at no cost at all, because the whole of the circulation of the water current is effected by the simple movement of the ship. I do not know whether you have observed this curious S-shaped canal, which runs right across the ship; the S shape at one end is turned to the bow of the ship, the other end of the S is turned towards the centre of the ship. It thus forms a continuous channel opening to the sea right through the ship by means of the condenser, and being of large area there, a very slight motion ahead with the entrance properly shaped sends a current of water right through the condenser. To show how modest a current, well applied and judiciously used as it is here, will accomplish that, he tells me that a small jet of steam when she is lying at anchor sending out the water at the after one of these mouths is quite enough to cause the current to maintain the vacuum at a height of 26 inches, which you know is a high condition for the vacuum of a steam engine. I say that the great reputation of our old correspondent Mr. Normand, who has so long held a high position at Havre, and who has already communicated to us so many valuable Papers, is thoroughly and entirely maintained by that so kindly read to us by his son.

Mr. Normand: I should like to say one word. It is not a new thing to utilise the velocity of a ship for the purpose of causing circulation of the water in the condenser; only when you use it you are obliged to have an immense quantity of surface condensation, because the condenser is not arranged so as to cause the resistance to be as small as possible. I should say that in ordinary condensers nothing is done to prevent the resistance of the water from being considerable. In these engines I have a very small surface in proportion to the steam used, and I have done it by having an immense quantity of water instead of surface. In that small engine I have more than 430 tons; that is to say about three or four times the general quantity of water that is passing through ordinary condensers. I am much obliged to Mr. Scott Russell for the remarks which he has made.

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ON YACHT MEASUREMENT.*

By E. C. Sterling, Esq.

[Read at the Seventeenth Session of the Institution of Naval Architects, 8th April, 1876; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

Most naval architects, having other occupations than yacht building, it is probably safe to assume that but few have turned their attention to that branch of the art. Those that have done so can hardly have failed to be struck at once by the vast importance of the Rule of Measurement under which a yacht has to sail, and with reference to which she must therefore be constructed. Few yachts but at some time in their career are raced, whilst a large proportion are built especially to that end: hence racing tonnage is the acknowledged criterion of size in yachts. In the case of cruisers which have never been raced builders' tonnage is quoted, and is sufficient to give a good notion of a vessel's size, for its results seldom differ much from what until the last few years was the only racing measurement, *viz.*: that of the Royal Thames Yacht Club, which first introduced the improvement of measuring length on deck instead of along the keel, thereby doing away with the premium on raking the stern-post—a practice which has naturally grown up, producing vessels absurd in form under water, and with a strong tendency to run off the wind; moreover, they were of course vastly larger than their nominal tonnage. There can be no doubt that the alteration in the Rule instead of being, as was by some predicted at the time, disastrous, has been on the contrary most beneficial. Some vessels built under the old Rule and altered under the new one are stated to be much improved by the change; and we know by experiment that the best vessels of the old days have not a chance against the modern specimens.

Displacement.

New measurement, as understood in the Mercantile Marine, is of course nearly related to displacement, of which hitherto no Yacht Club has taken cognizance. Many persons have thought that to adopt displacement as the standard would be a desirable

* Received 1st April, 1876.

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alteration; and it has the recommendation of being easily understood, and of being ascertainable by calculations of moderate length, with which all naval architects are familiar, and of laying down no hampering rules to interfere with the freedom of the designer's fancy as to form. On the other hand, it would inevitably induce those peculiarities which have been compendiously described as "all deck and dead wood." What proportions length, breadth, and depth might under such a system come to bear to one another it would perhaps be rash to say; but an obvious way of gaining size would be to make the overhang very considerable both forward and aft; whilst amidships the greatest beam would probably be far above the water-line, with a sharp turn to the bilge, very hollow garboards, and a deep keel. A vessel built to meet such a rule could hardly fail of the greatest success against any of our present vessels, as for her displacement tonnage she would have such great external dimensions and consequent power. It is hardly credible that a rule so definitely forcing peculiarities on the designer can be really a good one. At the same time this principle of displacement is at the root of several schemes which have been propounded in place of the present.

Royal Thames Yacht Club Rule.

This rule measures *length* on deck—from fore-part of stem to after-part of stern-post—as has been pointed out a vast improvement on the keel length of builders' measurement, but still taking no notice of counter however long. It then measures *breadth* wherever found greatest. To this no objection has ever been urged. It then deducts the breadth from the length; so that on whatever scale a circular vessel is of no size according to this rule. Moreover, that is not the only peculiarity which it developes:—50 *by* 50 *gives* 0 *tons;* 50 *by* 25 *gives* 83 *tons;* 50 *by* 30 *gives nearly* 96 *tons;* whilst 50 *by* 40 *gives* 85 *tons;* greater breadth giving less tonnage. Yet this rule is stated to be not merely admirable and equitable in practice but very scientific. With respect to depth, it departs widely from its own prescription as to length and breadth. Instead of measuring depth, as might have been expected, wherever found greatest, it does not measure at all but assumes depth equal to half breadth.

Now in the case of modern cutters and yawls, up to about 80 tons, there is but little difference between breadth and depth, so that for such vessels it would be far nearer the truth to say depth = breadth. The assumption is unfortunate in another respect—namely, that depth is far from varying directly as breadth; rather it varies inversely and for this sufficient reason: sail-carrying power must be got somehow; increase of beam means increase of nominal tonnage; increase of draught does not: accordingly, it not unfrequently accompanies decrease of beam. This rule is credited with scientific accuracy, although it makes a vessel of 6 feet draught the same size as one with 12 feet draught.

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Of course it should in fairness be remembered that the formula however indefensible has not been invented of late, but descended to us with the divisor 94.

Corinthian Rule.

The Corinthian Yacht Club, and following it the New Thames, have adopted a rule intended to remedy the crying evil of the older one in not measuring depth. These Clubs take length and breadth in the old way, measure depth up to top of covering board, multiply all together, and divide by 200. This divisor brings the figures back to something like what we have been used to, but of course is entirely arbitrary. However, the rule can take account of a circular vessel as well as of any other.

Sail Areas.

Classification by the measurement of sail areas has been advocated by some. Without insisting on the great if not insuperable difficulties of detail in working such a system, it must be noted that a fatal objection can be raised against its principle. The smaller and better-designed vessel has actually, in consequence of her superiority in one respect, to give time to the larger and worse-designed one—a principle possibly advantageous to the cruiser but fatal to the racer. It is, in fact, nothing but handicapping in disguise.

No sound edifice can be raised on foundations which are constantly and arbitrarily sliding about, and it is impossible to insist too strongly on the fact that measurement is concerned with size and size alone. The above are the most important suggestions which have been made; almost all others known to the writer being referable to some one of these heads—failing, therefore, either in not measuring an important dimension, or in depending on displacement, or in being some form of handicapping.

Now, respecting the practical working of the two rules at present in force in this country.

First—as to the one with the most numerous following, and generally called the Thames Rule. It might have been thought that to point out that two vessels of the same length and breadth, but one drawing twice as much water as the other, cannot be of the same size, would be sufficient by itself to condemn the rule. But then it is contended with at least apparent seriousness, that although the rule does not exactly measure size, it does measure *power*—that power being further explained to mean sail-carrying power. We must then ask if a foot or two of lead keel be added under a vessel's bottom, does that increase her sail-carrying power, or does it not? Obviously it does, and we then are entitled to ask, "Why should such additional size not be

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"measured and counted?"—a question which hitherto has failed to elicit any other answer than silent contempt. As a fact I am of opinion that many if not most yachts are unfairly classified for racing purposes owing to this defect in the rule. Nevertheless, with all its faults it has lately been adopted by a numerous and influential association of yachting men. This body has moreover superadded a detail of its own as to the manner of measuring length. It has decreed that if the stern-post go down vertically for a certain distance and then the heel go forward, the post thus having an elbow, length on deck shall be measured not to *where the post is* but to *where it would have been* had the line from the keel to the angle been produced. No machinery has yet been provided for enabling the measurers to carry out their duty in such cases. Sometimes they may want a very long arm for length on deck may become length *very far off deck*. The rule is obviously one for measuring *form* not *size*.

Finally, I say that the Thames Rule as amended enables a vessel, 1*st*, to diminish her tonnage by adding to her beam; 2*nd*, to increase her tonnage by cutting a piece off her vertical longitudinal section; 3*rd*, to retain her tonnage, though adding indefinitely to her draught and sail-carrying power. These facts are so striking that it may well be wondered how a rule with such glaring imperfections could have been tolerated, when once shown up and commented on. The reasons probably have been principally three: 1*st*, Comparatively few yachtsmen have studied the subject at all seriously, and many have just got so far as to believe that if their vessel's depth were measured instead of being only half the breadth it would turn out much greater, and so increase their tonnage; 2*nd*, Few indeed have any knowledge of design, or of how injuriously cramping the usual rule is—prescribing absolutely that a vessel shall be long, narrow and deep. 3*rd*, Every yacht that is built to suit the present rule, especially if at all successful, *ipso facto* renders its owner conservative and averse to admit the necessity of an alteration which may materially change his vessel's position.

The Corinthian Rule is an honest endeavour to correct some of the more flagrant shortcomings of the other, but it made the curious and indefensible mistake of fixing the place where depth is to be measured. So that in some cases it measures the greatest depth of the vessel, and in some cases it does not, according to the form of keel. Moreover, if sharp practice were resorted to, against which it is important to be guarded, it would be quite possible to make a groove in the keel for the chain, just where the measurement is to take place; by which means the figures would be decreased by the whole depth of the keel. The Committee of the Club has already decided to mend this rule by measuring the greatest depth wherever found. We may therefore fairly consider the principles on which the rule is founded. This anomaly is to be

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observed: it measures extreme dimensions, above and below water. Therefore its results ought to give extreme tonnage, not merely that of the immersed portion; but its authors appear to have been frightened at the large figures, and to have adopted an immense divisor, so as to bring the results to something like the usual amounts. This may be in some ways objectionable, but it is not unjust. Not unconnected with this is an objection which is worth serious consideration.

Of course everything that is measured is likely to be cut down to its minimum, therefore this rule will be unduly hard upon a most valuable quality (if it may be so termed) namely freeboard; in consequence vessels admirable in smooth water, but dangerously wet in a sea-way, will be encouraged. Did the advantages of freeboard go on increasing *ad infinitum*, this objection might be answered by the general statement "that where advantages are gained by extra dimensions it is in justice impossible to "avoid including them in the reckoning, and it is in fact highly improbable that an "element so useful as freeboard for giving additional comfort and stability even in smooth "water would be unduly sacrificed." But there is another point of view from which it might seem wiser not to measure above the load water-line—namely, that the value of freeboard does not go on increasing indefinitely; that the point where the raising of weights, of deck, &c., and centre of effort of sails counterbalances the advantages of height of side, is presently reached; and that therefore for all practical purposes no harm nor injustice would be done by allowing freeboard to go unmeasured and therefore uncounted. This is a point on which the opinion of scientific men would be most interesting and valuable. There is one advantage in measuring the whole vessel instead of stopping at load water-line; namely, that no alteration of trim, shifting, taking in or putting out ballast would make any difference. For practical purposes, therefore, there can be no doubt the Corinthian Rule is the simpler.

The same objection which is made to measuring freeboard is made to measuring draught—that the construction of unduly shallow vessels is thereby encouraged, of vessels deficient in depth to the extent of being unsafe. The answer made above is of double force here, and we may safely repeat *mutatis mutandis*, "Where advantages are gained "by extra dimensions it is impossible to avoid including them in the reckoning, and "it is in fact highly improbable that an element so important as draught for giving "stability and weatherliness would be unduly sacrificed."

One objection the rule appears open to from which escape is far from easy; it is this, that by multiplying the dimensions together depth comes to be of equal value with breadth. Now few yachting men, even of those who hold that depth should be measured, would be disposed to admit it quite on even terms, did any way out of the difficulty present itself. Here again professional counsel would be of great value.

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There is another objection, not yet alluded to, which applies equally to Thames and Corinthian Rules, *viz.:* measurement for length only goes to after part of stern-post, and thus admits any amount of counter, even when its touch is far below the water so that it really forms part of the vessel's body. In any case it is but an encumbrance for sea-going—a trap to catch seas which would break clear were it absent. Why not measure to the taffrail, and so strike a blow which such gingerbread would not long survive?

It only remains to insist on what has already been touched upon, the importance of establishing a rule which besides being just should not in any way pretend to *measure* or *dictate form* to the designer. With such objects it must in my opinion follow the Corinthian in dealing with *extreme dimensions.* Could such a rule be generally established we should learn much of which we are now practically ignorant—for example: whether within given dimensions more speed could be obtained by greater displacement and more sail, or by less of each. Again, whether large displacement were wise, either through increased area of mid-section, or through more straight of breadth, or both. Again, cutting off the counter would permit it to be ascertained whether cleanness of delivery were better achieved by fine buttock-lines as at present, or by fine water-lines like the entrance. To tax depth would very likely tend to diminish that extreme to which we now have recourse—a prospect far from being terrible. If good boats can be made with lighter draught than at present, which is not at all improbable, nothing could more conduce to the convenience of yachtsmen, who so constantly work shallow waters and use tidal harbours.

As a matter of history it would appear that one of the main reasons for the abandonment of the old system of builders' measurement was that it encouraged the construction of unsafe ships.

The present Thames Rule throws all its weight into forcing yachts to be made long, deep, and narrow; possibly such is not the best type, but until we have a radical reform no other can be tried. The rule of measurement cannot make a good vessel though it may go far to mar one, and the best rule interferes least.

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DISCUSSION.

Rear-Admiral J. H. SELWYN: It is only a very few words that I have to say, my Lord, and it is with regard to what is stated on page 315. You find there that "the greatest beam would probably be "far above the water-line with a sharp turn to the bilge, very hollow garboards, and a deep keel. "A vessel built to meet such a rule could hardly fail of the greatest success against any of our present "vessels." Now, that is very nearly the model of a gunboat that I saw here the other day. I have seen a vessel constructed by Mr. John Macintosh which he called a sailing machine. She was built very much on the idea of the enormous beam that is talked of in circular ironclads, and she was so fast that nothing could compete with her. She was a skimming dish and perfectly stable, because she had beam enough to stand any amount of sail. She was fast, she drew but little water, and she only came to grief by one day going over a warp lying out in the river, and tilting herself up so that she went down. She had very large deck and very little hatchway; she was not dangerous at sea because of her construction; for you know the very safest form that you can possibly get at sea is that of the raft. Provided that you make the vessel tight against the admission of water, there is no vessel that will make such good weather as the vessel which floats at the angle of the wave at all times. That is the peculiarity of the raft, and we cannot beat it. How far we have gone in long and deep vessels may be easily seen by the proportions of the present ocean steamers. I think we have gone very nearly to the extreme point at which they are available. We have never tried, possibly on account of the tonnage rules on yachts, the sailing machine built to skim over the water; but I hope there may be such alterations in some of the yacht rules as may enable such vessels to be tried. What we want to know is how to get the greatest speed out of a yacht with given dimensions and given tonnage. I do not think it is fair to adopt any arbitrary rule of measurement other than the contained tonnage of the vessel, which is a fair measurement of her capacity.

Mr. J. SCOTT RUSSELL, F.R.S.: Do you mean the room inside the vessel?

Rear-Admiral SELWYN: I mean the room inside the vessel. That is a fair measurement of everything. I do not see why we should resort to all sorts of devices such as have been spoken of by the author of this Paper, in order to get at an arbitrary measurement which will have the effect of cutting somebody's throat. Surely yachtsmen, like other racing men, desire to get the extremest speed that is obtainable on the water, and if that can be done under an open rule the sooner we have it the better for the ascertainment of the speed.

Mr. HENRY LIGGINS: I read a Paper on this subject before this Institution some years ago; but my experience in this matter is derived from having been for a number of years one of the official measurers of the Royal Thames Yacht Club; and when I tell you that this Rule of the Royal Thames Yacht Club—which is not quite fairly stated here by the author of the Paper—was designed and invented, if I may use the phrase, by a nobleman who for many years was looked upon as the most scientific and most practical yachtsman in England; and to this very day that late nobleman's opinion on all yachting matters is looked up to with the highest respect. I allude to the late Lord De Ros, than whom we have had no more experienced or thoroughly scientific yachtsman. You will agree with me, that a rule to meet every difficulty of this most difficult subject, which was brought out by that

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experience which a long life enabled him to acquire, is not a rule to be lightly passed over. I know too much of the subject to venture to criticise this Paper thoroughly, which I have not seen until I heard it read. The author makes a great point of measuring two features, and a compromise for the third dimension of the yacht—the depth. I will give you the reason why Lord De Ros schemed that plan; it was with a view to keeping up a high standard of efficient vessels; it was expressly done to give a great latitude to the builder, and at the same time to prevent him from producing a racing machine. We know perfectly well that we can get faster yachts than any in England; but we also know that, if we attempt it, we at once get a racing machine which is valueless for all other purposes except for racing; and as the opening clause of the Rules of the Royal Thames Yacht Club states, this Club was instituted some forty years ago or more for the purpose of improving yacht building and sailing on the River Thames. Therefore, this compromise of the three dimensions of the yacht—length, breadth, and depth—was invented by Lord De Ros with a view to preventing a useless class of vessels being introduced; and it has been copied, practically, by all the great racing nations of the globe. The United States have tried every sort of rule, and so have we. They have come down to a different rule than ours, and a worse one, for they only measure two of the dimensions. The New York Yacht Club measure length and breadth on the water-line, and ignore depth altogether. And what is the result? They get vessels much of the class which Admiral Selwyn advocates; and he will not be surprised when I tell him that before the wind they are the fastest vessels in the world; but then, as you know, it does not require much skill to make a washing-tub go fast before the wind; the difficulty is to make a vessel go fast on the wind; and when a New York Club vessel meets with a deep-keeled Royal Thames Yacht Club vessel the New Yorker finds herself nowhere; she cannot hold the wind; and that is the reason why they have adopted the old English plan of deepening their draught of water by the application of our old English invention of drop keels. Those drop keels are most objectionable in a variety of ways. They cause leakage and unfairness, because you may drop them to any extent and make a vessel so unfair that she is an altered vessel: she is one day running before the wind, with her keel up and a very shallow draught of water; and she is another day a very deep-draught vessel, going to windward in a way that no other can do. That is not a vessel but a racing machine; and with a view to prevent that useless kind of craft the Royal Thames Yacht Club Rule now stands prominently before other rules. The author mentions the new Rule of the New Thames Yacht Club. That is an attempt to measure the external capacity of the vessel, and what is the result of it? This is either the third or fourth summer—I am not sure which—that that rule has been attempted to be used; I will not say it has been in use, because all the yachting gentlemen of England have refused to abide by it. Count Batthyany, Major Ewing, Mr. Ashbury, Mr. Broadwood, and all the leading yachtsmen positively refused the year before last to let their vessels sail; and I was down the Thames at one of the intended matches of the New Thames Yacht Club when the vessels were to sail under that rule, and although they were all in line they refused to start under it. That is the result of the New Thames Yacht Club Rule, which is an attempt to measure the real capacity of the yacht—that is, external capacity. It is all very well to say that the fairest way is to measure the capacity of the yacht, but I will tell you how deceit might be practised as to the tonnage. If I have a yacht say of 60 tons internal capacity—a racing cutter—it would be very easy for me to double her inside with the lightest specific gravity wood I can get—fir, or even cork—and make her sides, instead of 9 or 10 inches or a foot thick, 2 feet thick. By that means I should get a very small vessel inside, and a very large one outside; and

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there would be every amount of possible dead-wood in the stern and the run aft and the forward parts, so as to make her measure as small as possible inside; she would be really a large vessel outside, and a small one in, with an enormous sail-carrying power. That would certainly damage the vessel, but it would make her 40 or 50 tons instead of 60 tons for her sailing purposes, and that is to be avoided.

Mr. J. Scott Russell: You are talking against inside measurement in that case.

Mr. Liggins: I am talking with regard to Mr. Moorsom's rule of inside measurement of capacity. That would lead to as much abuse as the raking stern-post did, which the late Mr. Ditchburn said in this room he had invented with a view to defeat the tonnage. It is obvious that when the length of keel is taken, and you put a stern-post like that [*describing*], you have a very short keel; but if you put on a stern-post upright, or nearly so, you get a very long keel. That was the origin and that was the intention of raking stern-posts. Unfortunately the fashion of the thing continues to this day, and raking stern-posts and all their objections are still adopted by racing yacht builders, without giving any thought or reason for it. The only two rules that really have stood the test of time are the Rule of the New York Yacht Club, which takes length and breadth only and ignores depth altogether, and the Royal Thames Yacht Club Rule, which takes length on deck at a very fair place, and the greatest beam wherever found with a compromise of half the breadth in lieu of depth. I do not think we are likely for a very long time to see any rule that will supersede it. It has stood the test of many years in various countries. I may observe that in most of the matches in France the French Yacht Clubs use it. I have sailed matches in Havre that have been sailed under that rule, simply because the French have not in their ingenious way been able to invent anything better. I am not able to say anything about this Corinthian Rule, because it has only just come under my notice. The sail area plan has been tried in England some thirty or forty years ago, but there were so many objections to it that it was abandoned. Certainly, having had the literature of this subject before me pretty frequently, my opinion is that our yacht sailing owners are quite justified in holding as tightly as they do to the present Royal Thames Yacht Club Rule.

Mr. J. Scott Russell: I must say that I see no way of getting out of the use of length and breadth simply as the two first great elements of yacht construction; but I do see a little difficulty when you come to the third element—depth, as to how to use it, because I do not see the great harm of allowing you to choose what depth you like, and, therefore, I do not see that you ought to restrict the depth—and if you do not restrict the depth at all, why should you take depth at all into consideration? That therefore, if I am right, leads us to take the length as Element No. 1, the breadth as Element No. 2, and we now come to No. 3. What will you do with No. 3, because No. 3 gives capacity? Hitherto we have only taken two elements—one of length, the element of little resistance; another of breadth, which is as we know the element of sail-carrying power; but to allow the depth to enter into it directly would not be wise. Therefore I think we are driven into a corner against our will perhaps, and that although we do not allow true depth to come into the ship, yet in order to get our cubic volume or cubic number (call it what you like) we must introduce a third element. Now I think it is very dangerous to take that third element from any dimension whatever that you can measure of a ship; and if you do not do that, and if you must take a third element it must be a fictitious one, and what is that fictitious one which we have all taken? We have all taken the fictitious one of taking as the third element half the beam. If we are to take a third element, that is in order to get the square

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of the beam somehow, it is just as well to take half the beam as any other fraction, because the multiple sets that all right. I do not see any way out of the ordinary very simple rule of yacht measuring. I do not know which Club it belongs to more than another, because I have very nearly forgotten what are the rules of the different Clubs; but I see now that to take the length of the ship honestly, the beam of the ship where it is biggest, and to multiply that instead of by the depth by some function, say half the beam, is the only way of laying down fair conditions as to the dimensions of a yacht which leave you free. I think it is necessary you should not take volumes at all for this reason: consider what you are doing in designing a yacht for the sake of speed; you cannot have less than a certain length, and therefore you take that length in order to get speed and fine lines. Therefore, of course, you want to get length. Then you who lay down the law want to limit the length—that is to say you do not want me with a longer length than you have, to record my ship as less in tonnage. Then you go to the next element, which is breadth, and you do not want me by any dodge to have more breadth than you without paying for it; therefore, you take breadth as my limit. Now I would go in with you for depth if I could see any possible depth that you would take; but whatever depth you take the yacht builder would take a greater depth than you, and as you cannot get below the yacht builder's cleverness in depth I think you must give it up altogether. Then, giving up absolute depth as absurd and impossible, because they put the deep place where you do not want it and the shallow place where you do not want it, we must take this arbitrary depth, and I have the conviction that a man who is only confined to these limits, which you say are the limits of the Thames Yacht Club, has nothing to complain of, and I do not think it likely to meet with any unfair competition. I do not therefore see how we can lay down the law any further than that.

Mr. LIGGINS: Allow me to make just one observation. I think the remarks of Mr. Scott Russell are most valuable to the Racing Clubs of the United Kingdom; because, although the rule is called the Royal Thames Yacht Club Rule, and was invented by a distinguished member of that Club, I may tell you that, as a rule, every Yacht Club in the three Kingdoms adopts that—the Royal Yacht Squadron and every other Club under it. It is a most valuable confirmation of Lord De Ros's great ingenuity that it should be confirmed by such an eminent ship constructor as Mr. Scott Russell.

Mr. ANDREW THOMSON: There are one or two things I should like to say upon the question as to the rule. In the first place, as Mr. Liggins said, yachting was not instituted entirely for yacht racing—the rule of measurement was not intended entirely for that, but it was intended to bring forth a better class of yacht as well; therefore that to a measure ties you to a particular type of vessel, without a certain amount of depth. You cannot have small yachts, at least with any amount of comfort, inboard; and therefore depth being taken into consideration in small vessels would limit that comfort.

Mr. J. SCOTT RUSSELL: You mean actual depth, not fictitious depth?

Mr. THOMSON: Yes; actual depth. But I think, as depth gives the vessel a greater amount of lateral resistance, and therefore weatherly qualities, we should adopt some penalty; and probably a greater penalty than the Royal Thames Yacht Club imposes. Perhaps the better way of taking any measurement would be by displacement. The only difficulty is in finding some practical way of doing it. Mr. Lee, of the New Thames Yacht Club, some time ago was an advocate for taking depth into consideration, and suggested that a floating dock should be used, and that the vessel should be placed in this dock and her actual weight taken with all her gearing. This, no doubt, would give the builder the

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choice of any form that he wished to build; and if it could be done in a simple practical way, I believe it would be the best measurement that we could possibly get.

Mr. J. Scott Russell: It would cost money, I fear.

Mr. Thomson: Probably that is the great objection. I do not know that a question of money, in so very important a matter as yacht measurement, should be allowed to stand in the way at all. I think it would be quite possible to put up a few docks of a similar kind to what Mr. Lee has described at various points, where yachts could go and be measured; and after they had been once measured, they might vary slightly—so far as the ballast and so on was concerned—but, if the load line was measured on them, that variation could easily be calculated, without putting them into dock again.

Mr. J. Scott Russell: It could be measured accurately outside.

Mr. Thomson: It could be measured accurately, but I think taking the actual displacement of the vessel is better than any measurement taken by the foot-rule.

Mr. J. Scott Russell: Better; but then there is the question of money.

Mr. Thomson: I think money is of very little consequence, because when people go in for yacht racing they care very little how much they spend on a yacht. Very few men who go in for yacht racing consider the expense.

Mr. J. Scott Russell: A careful outside measurement is as good as any other.

Mr. Thomson: In what manner would you propose to take an accurate measurement outside? Would not the question of using lead and iron ballast affect that measurement very greatly?

Mr. J. Scott Russell: Not so—that is just the point of it.

Mr. Thomson: I fancy you would find that lead keels would measure much less than iron ones for the displacement. Their weight is exactly the same. A ton of iron will displace the same as a ton of lead. I have nothing more to say, except that I think if any step could be taken for proposing some scheme for taking displacement it would work a great reform.

Mr. Frederick K. Barnes: My Lord, I should just like to say, on the question of tonnage, that it appears to me all you want to determine is the relative sizes or weights of certain yachts or vessels. When once you determine whether you will take size or bulk (by internal or external measurement) or weight as a basis, either of those quantities might be obtained accurately by well-known rules—one being invariable. The other, *viz.* weight, would be liable to constant alteration. The owner of a yacht would not, perhaps, like the tonnage of his yacht altered whenever he chose to alter his ballast, or the number of persons he carries, or any other weight in the ship whether it formed part of the hull or equipment of crew or of passenger; but this must be done if weight or displacement is taken as the tonnage. This forms the objection to take the weight or displacement as a basis. I think therefore it is essential in the first place for Yacht Clubs to determine which of those two measurements they would adopt—weight or size. If the latter, the measurement might be internal or external, both of which could be readily ascertained and fraudulent measurements prevented. When this has been agreed upon you must leave the rest to the ingenuity of the naval architect. In fact, as regards safety and speed of vessels of given tonnage, that must be left, as it seems to me, to the naval architect; and the man who can produce the best ship, of either the smallest size or the smallest weight, is the man you ought to employ to build your yachts.

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Mr. BENJAMIN MARTELL: I should like to say a word or two on this subject. It has been suggested by Mr. Thomson that probably the best measure that could be taken would be either the displacement or the internal capacity.

Mr. THOMSON: Not the internal capacity.

Mr. J. SCOTT RUSSELL: External capacity.

Mr. MARTELL: Then it is the displacement. I think it was Mr. Liggins who in the first instance said that there might be great difficulty in obtaining the internal capacity of a vessel, because her builders would lay themselves out and be anxious to evade any such rule. I cannot see any difficulty, because at this moment Moorsom's Rule, as applied for the purpose of measuring mercantile ships, is a very fair indication indeed of the internal capacity of ships; and the mere fact of some owners or builders attempting to put an internal lining of a material of light specific gravity, such as cork, could easily be obviated. The Board of Trade by their rule now protect themselves by only allowing a certain thickness of battens on the frame of the ship. They also restrict the limber strake to a certain thickness. We know that formerly the rules were evaded continually. A builder after his ship was finished, and the tonnage came on a certain scale to a little larger than he had contracted for, had only to put on a little thicker battens and an extra thickness of ceiling, and by altering the breadth in that way he obtained a tonnage less than before. But the Government, in order to prevent any such evasion as that, restricted the thickness of battens to something like two inches, and it does not matter what you put on inside if you restrict the thickness of your vessel from the external part to the internal part. That would obviate any kind of evasion whatever, because you would then by those means get the true internal capacity of the vessel. I state that merely to show that there would be no practical difficulty on that point as far as I can see. Then with reference to the displacement—if really weight is to be taken—I cannot see the slightest difficulty in that, because when a vessel is completed (and it is not necessary to measure her until she is actually completed) and you have correct drawings of the vessel, you can get her correct draught of water to a quarter of an inch; therefore I cannot see what difficulty there is in calculating the exact displacement. The old rule for tonnage was to ignore the depth, and only take length and breadth; but no improvement was then made in shipbuilding in this country, and it was only when we did away with that restriction, and the whole capacity of the vessel was taken into consideration, that any improvement in naval architecture took place, and that we were able to compete with the Americans and others who had been building ships better than ours. I do not see what improvement can take place in the general form of vessels of that kind unless you take the whole dimensions. I believe the Royal Yacht Squadron was taken under the patronage of Royalty with a view to improve the form of vessels; and therefore if that form cannot be improved unless you take in the whole capacity of the vessel, really I think some means of that kind should be adopted with a view to the general improvement of vessels. And I must say that I cannot see any difficulty in ascertaining either the capacity or the displacement.

Mr. LIGGINS: It varies day by day. A yacht will sail with 20 tons more ballast to-morrow than she would to-day, according to the probabilities of the weather, and that is the reason why weight would not answer.

Mr. MARTELL: It does not matter whether you take weight of hull or weight of ballast. If you take the weight it is precisely the same.

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Mr. LIGGINS: But then you could not measure her to the satisfaction of your opponents.

Mr. J. SCOTT RUSSELL: I should like to ask one question, and that is, what advantage should we derive if we could perfectly ascertain the exact cubic capacity of the body of the ship in the future of yacht building? Should we derive any benefit from the weighing system you have proposed, or the measuring system by which we could get the weight without weighing? What improvement do you think that would make?

Mr. THOMSON: My reason for proposing that the weight should be taken is, that it does not tie the builder to any one particular form of vessel; so long as there is a particular weight and displacement he can build it to any form he likes.

Mr. J. SCOTT RUSSELL: You really think that that is the most convenient basis on which to build?

Mr. THOMSON: That is my idea.

Mr. JOHN HARVEY: My Lord and Gentlemen, I feel rather diffident in rising to make a few observations after so many able speakers on this question; but being a yacht builder, and more acquainted with yacht building than most of the gentlemen present, I may be excused for making a few remarks. First of all, looking to the suggestions of Mr. Sterling's Paper, as to the proper mode of arriving at the tonnage of a yacht, I think the principal thing to decide is whether displacement should or should not be taken as the basis. As a yacht builder I should not (and I think all naval architects will agree with me) object to displacement being taken as the basis of yacht measurement, although there would be considerable difficulty as has been pointed out in arriving at this point, owing to the continual alterations made by the removal and replacing of weights on board racing yachts. It is this question of displacement, or—as the New Thames Yacht Club system of admeasurement puts it—main depth of ship in and out of the water, that gives cause for fear among yacht-racing men, and makes them afraid, as Mr. Liggins says, to adopt it. The fear they picture to themselves is that, as contended by our friend Admiral Selwyn in his remarks, nothing is safer in a sea-way than a raft. I may say that he is perfectly right, and that a raft is a very safe thing; but then we look for yachts to be something more than a raft, which is all very well for hardy old tars to be washed about upon. Yachts are or should be built for comfort, and as unlike a raft, or what I am afraid they would become if displacement is taken as a basis for tonnage, as possible. Yachts I look upon as pleasure vessels, in and on which when our health fails us we can get recruited by the comforts to be had by good accommodation as well as sea-going qualities. I therefore do not agree that naval architects should be restricted in the least in their designs for yachts, so far as depth and bulk, whether in the water or out is concerned. We have got our shores and harbours around our coast to limit the depth to which we can build our yachts. From 13 to 14 feet is about all the draughts of water we can give a yacht; and those who do not like to go to 13 or 14 feet can have 12 feet, and get beaten by those who go as far as 13 or 14 feet draught of water in constructing their yachts. To my mind therefore in measuring depth, or taking a yacht's displacement or whole bulk as basis for arriving at her tonnage, would in the future produce a much less comfortable yacht than the general type of yachts are now; and if you will allow me I will describe to you a yacht of rather peculiar profile and dimensions which I have just lately theoretically advised her builder upon, the object of her owner and builders being to construct the easiest sea-going and fastest yacht that could be constructed. The dimensions of this yacht stated roughly are, length in the load line 100 feet, whilst she is but 84 feet on the keel, her main breadth being but 17 feet; her depth exceeding her breadth 2 feet; her draught of water aft 14 feet

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6 inches, and forward but 1 foot 6 inches. She has an upright stern-post, and a stern some 20 feet long, 16 feet in length by 7 feet in depth of the stern being under water. This yacht is the easiest vessel at sea and the quickest in stays, whilst at the same time she cleaves and leaves the water smoother than any vessel ever sailed in, and I contend that she is a good illustration of the fallacy of making a strict rule for the system of admeasurement as proposed by the Paper read. I think the provision made by the Yacht-Racing Association, which takes due note of any peculiarities, whether as fore rake, or projecting-under-water sterns, are all that are required in addition to the Royal Thames Yacht Club mode of admeasurement. Referring to the remarks made by Mr. Liggins, I do not think he gives us credit for the thought we have to give to the general principles of yacht building as scientific men and builders; in fact it would appear from his remarks that he does not think our designs are on any scientific basis whatever. As a naval architect, I know these designs require great thought, and I do not think Mr. Liggins can be one himself, or he would not make such remarks as he has; for I contend, in reply to his remarks about raking stern-posts, that a vessel can have a raking stern-post, and be as good a sea-boat, and handle as well as if she had no rake. With this opinion I am persuaded the naval architects around me and more particularly Mr. J. Scott Russell will agree. It is now several years that I have given this branch of study my strictest attention, and in conjunction with the late Mr. Fountaine, and the late Superintendent of H.M. Coast-Guard Tenders, Mr. Peake, and the gentleman who succeeded him, Mr. Welch, I have spent many pleasant hours on this ever-engaging topic; and feel now in designing vessels that if such main centres as buoyancy, lateral resistance, and the effort of the sails are kept in due relation with each other, there is the greatest certainty of turning out what may be required for a good sea-going and fast yacht. And in conclusion, on this head I beg to add that the best racing yacht makes the best cruiser, although Mr. Liggins has likened racing yachts to racing machines. Some remarks have been made about gentlemen who wished yachts built being regardless of the expense which they incurred; but I beg to say that with some gentlemen I have found it quite the reverse, and that in a great many ways builders are restricted in carrying out their ideas, more particularly in a pecuniary sense. In this particular I cannot but say that Mr. Bentall (the owner of the peculiar yacht above roughly described) gave his vessel, the *Jullanâr*, all she required. But in this case, as I have remarked before, I was merely consulted and advised as to her model, whilst Mr. Bentall built her himself.

Rear-Admiral SELWYN: Will you tell us something about the position of the masts in the yacht you have been describing to us?

Mr. HARVEY: She is a yawl: I would have made her a schooner. She carries a very short mast for her broadside length because she is very narrow.

Mr. JOHN A. WELCH: I have been a Superintendent of Admiralty Coast-Guard Cruisers, and I have devoted some years of my life to the consideration of the subject of this class of vessel—that is to say, a yachting vessel. In the Service we used to have a great many cutters of various descriptions; and in former times they did great service. There are a great many naval officers here present who know what in early years those vessels used to perform; but the forms of vessels have of late years changed very much, especially with respect to pilot cutters and all those fast vessels which had to go out to sea to earn their living by their speed, and that caused something like a revolution with respect to the description of vessel. It became necessary to fine the lines of the Coast-Guard vessels, and that duty devolved upon my predecessor, but more especially upon me because his vessels were rather full. I found very great

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difficulty at starting to improve upon the old type; and this was the difficulty that presented itself. Taking a small class vessel, such as a 60-ton cutter, I found that she could go to sea, and keep the sea, in all weathers, and perform all her duty, with the small ballast of 18 tons. I was called upon —and that put me upon my mettle—to produce a vessel that should beat that one in every way; and I had to do this, to make her a larger vessel, to make her draw more water, and to put more ballast into her. Notwithstanding that I studied the forms of those vessels, and found that, whereas the round form of midship section gave the centre of buoyancy in a certain position, by giving the hollow form it would raise the centre of buoyancy, and that was equivalent to lowering the centre of gravity of weight. Therefore I gained some proportionate amount, notwithstanding I could not beat the old vessel on the question of size for size, with the respective ballast. There seems to me to hinge the question of yachts. Those vessels I alluded to were improved simply by raising the centre of buoyancy, and raising the centre of buoyancy meant really an improvement in their forms. That gives us the form of section, and then the form of the water-line. We had to go into a longer vessel in order to get greater speed and more weatherly qualities by the increased draught; so that at the expense of the various points I have mentioned we gained a positive improvement in the type of vessel. It is a large subject, and a subject which I never thought in this Institution of bringing before the notice of the Members, because some of the rules may be regarded as empirical; but still there is a great deal in what Mr. Harvey says, as we have found out by experience that if we were to take the middle of the load water-line of the vessel and work out her centre of buoyancy, we should then find in what position her centre of lateral resistance ought to be in order to have all the necessary qualities for a racing yacht—*i.e.*, these three centres ought to be in a direct line. I had not the advantage of hearing a great portion of the Paper, but I may corroborate what is said, that there is a great deal in it. It is all inductive. We reason from one thing to another, but we are able to arrive at a result whereby we can form an opinion as to the form of vessel to adopt; and no one better than Mr. Scott Russell can appreciate what I say in that respect so as to make a proper comparison. The displacement in a great measure is the comparison, because in builders' tonnage that is our old way of measuring ships or yachts—then we have displacement proportionate to it. In a vessel of 60 tons her displacement may be about 60 tons. She may be a comparatively full vessel, but as you go below that displacement you have got a fine vessel; and if with a fine vessel you can combine those various elements, then you give her all those qualities which are necessary for complete success—the principal being weatherliness and handiness. Those points have to be studied, and those are the very points which make them specialities with such shipbuilders as Mr. Harvey and others with whom I have been thrown into connection.

The PRESIDENT: Mr. Welch has said, and said truly, that this is a very large subject; but I really cannot help reminding you that we are making it rather larger than it was intended to be. The question before the Meeting is the simple one as to the best mode of measuring the tonnage of yachts, and I am afraid we are travelling beyond that, and are going into various other questions. I hope that we shall only consider at this moment what is the best mode of measuring the tonnage of yachts.

Mr. WILLIAM DENNY: I must protest against what has been said with reference to this question not requiring to be dealt with in a scientific manner. I am sure we are most anxious that the measurement should be as scientific as the building of the yacht is. Before the Institution there are two measurements that have been applied to yachts, and they are both scientific; the one being displacement, and the other

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the internal capacity. Both of them are open to objections. The internal capacity is open to the objection which has been well stated by one of the speakers, that the side may be made of any thickness; the displacement is open to the objection that the draught and the displacement may be changed. There is no difficulty in arriving at the displacement, and one way in which it could be done easily is that the ship should be officially calculated to begin with; that her scale of displacement should be ascertained, from which her displacement could be found easily at any draught. There would be no difficulty in that. Still, if there were a difficulty, I think Mr. Martell's suggestion a most valuable one, that the internal capacity should be taken with a limitation of thickness. He says that Government now limits the thickness of the ceiling. There is no reason why the whole thickness of side should not be limited to a thickness sufficient for any particular work, and I think that the measurement lies in one of two directions, either in an official displacement scale that could be referred to for any draught, or a fixed measurement of tonnage according to Mr. Martell's suggestion, based upon her internal capacity with a limit of thickness of side, which would be an unchangeable thing.

Mr. WILLIAM AUSTIN, C.E.: My Lord and Gentlemen, I would beg most respectfully to call the attention of the Meeting to this point. I think the object of inquiry will be met by reading the four or five past numbers of the *Navy*, in which there were some very splendid letters, written by an eminent practical man in every sense of the word—Mr. Benjamin Sharp. I have not the pleasure of knowing the gentleman, but I have had a great deal to do with ships and shipping matters, and especially with the construction of ships. The question before the Meeting is, whether for the purpose of ascertaining the tonnage of a ship you should measure by the present rule, which is called "Moorsom's Rule," which takes length, breadth, and depth. Now a ship varies so very considerably both internally and externally by tumbling in sharp or flat that it makes a vast deal of difference as to her depth. A ship might probably be the same length in proportion to her beam, but when her depth is altered it makes a vast deal of difference; and, therefore, it depends then upon a factor as to what the amount of tonnage shall be. The way in which ships are calculated is this:—They take the extreme length from stem to stern, they take the broadest part of the beam, and then they measure the depth from the deck to the keel, and the factor of division is 130, and that is supposed to give tons displacement. That has been the arbitrary rule up to the present time; but Mr. Sharp proposes a far better plan, and that is to float ships into a dock and have a gauge by which their external displacement will be found immediately. There will be no difficulty then in any ship being gauged; she will pass through a gauge dock in approaching other docks or other harbours, and it could always, after launching, be proved what her displacement was both before loading and afterwards. I think that is most valuable information, and if your Lordship has not seen them I think those four or five letters will well repay perusal. I do not, of course, take any credit or claim any merit in the affair for myself, but I desire to say that I think Mr. Sharp has hit the right nail on the head, and has discovered the right way of obtaining the displacement and the true tonnage of ships.

Mr. E. C. STERLING: I must ask, in the first place, to put myself right with the naval architects present, because they are the last people with whom I should wish to have any quarrel. It has been suggested that I implied in my Paper that they did not know how to measure displacement. I will just read three lines at the beginning of the Paper, to show that I did not suggest that for an instant. What I do say is, "Many persons have thought that to adopt displacement as the standard would be a desirable "alteration; and it has the recommendation of being easily understood, and of being ascertainable by

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" calculations of moderate length, with which all naval architects are familiar, and of laying down no " hampering rules to interfere with the freedom of the designer's fancy as to form." A good deal of the question that has been discussed since I came into the room has been as though there was some real difficulty in ascertaining the displacement. If I may make a diagram, I will show you one thing which has not been touched upon yet. I should not like to destroy the illustration of Mr. Harvey, because it seems to me to prove in the most conclusive manner that I have been eminently right in one thing, namely, that the present rule of measuring the stern-post instead of taking in the counter was utterly insufficient. I did not expect that anyone who objected to what I said would so entirely prove my case as it is proved by that drawing. One of the great points which we want to get at is that the architect shall be as little as possible hampered in his design. Therefore displacement is a good thing; but I maintain that with displacement this is the section which we shall have beyond all possible doubt. [*illustrating it*]. That shows an absurdly small displacement, and we shall have this enormous vessel. There is obviously no accommodation in that vessel. I think nobody can have any doubt that a vessel with a good deep keel will have all the qualities of an ordinary centre-board yacht, but she will be, beyond all reaching, fast in smooth water on any point of sailing; but she will also be very bad in a sea-way; and with a head wind she will bob about and go up and down, and will not go on. I maintain that displacement inevitably produces that form in a yacht, in spite of all that has been said as to its allowing anything to be done. It prescribes that, and that is really my main objection to displacement.

Mr. WELCH: It is a good form.

Mr. STERLING: For certain purposes; but it has not got the comfort which is important in a yacht, and it is not a good vessel for sea-going in rough weather.

Mr. J. SCOTT RUSSELL: And not a weight-carrying ship.

Mr. LIGGINS: Not a fine sea-going vessel.

Mr. STERLING: It is very difficult, indeed, to say with that what sort of relation the two vessels bear to one another. One man will contrive to overhang as much as that.

Mr. LIGGINS: It is a racing machine.

Mr. STERLING: It will, as has been said long ago, make the vessel all deck and dead-wood. In fact, it will be little else than a raft with a deep keel; and surely that should not be the thing to which we ought to tend. I am very sorry, I confess, that the whole Discussion since I came into the room has gone on the question of displacement; and that no gentleman has objected, as I hoped he would—and given his reason for objecting—to the Corinthian Rule adopted by the New Thames Yacht Club. That has been simply put aside, and the whole question has turned on the question of displacement. I think it is very unfortunate that not a word has been said with regard to the Corinthian Rule. That is really the only practical effort that has been made to alter what many of us believe to be a thoroughly bad rule; and I must say I did not expect that question would be shied, as it is so apt to be among yachtsmen. It has been said, as we all know, that the Royal Thames Yacht Club Rule is the best; and I was in hopes that some reason would have been given here to show why the other is bad.

Mr. J. SCOTT RUSSELL: I do not think you could have heard what I said, for I certainly did not shirk the question.

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ON A NEW STEERING GEAR.*

By G. L. Watson, Esq., Naval Architect.

[Read at the Seventeenth Session of the Institution of Naval Architects, 8th April, 1876; the Right Hon. Lord Hampton, G.C.B., D.C.L., President, in the Chair.]

I have considerable diffidence in submitting to such a body as the Institution of Naval Architects any scheme purporting to be an improvement on the method of steering vessels; for I am aware that among those present there must be many who have given their careful attention to this particular branch of naval tactics, and are therefore better able to deal with the subject than I can be. At the same time, while *all* naval architects are more or less interested in the manœuvring of vessels, but a few have busied themselves in examining the *means* by which they are to be manœuvred; and while they have investigated the nature of the rudder's action on the water, have left the study of the steering gear's action on the rudder to the engineer or practical shipbuilder. This I am sure has been a mistake. For while these gentlemen have produced machines, which are more or less perfect, for turning a shaft on which there is a *constant* load, they have apparently overlooked a fact of which we are all aware—*viz.*, that the resistance increases enormously as the rudder is put over to its extreme angles; and although in one or two of these gears the power brought to bear on the rudder at any angle is as the difference between the secant of that angle and that of the secant of the angle immediately adjoining it, the resistance on the rudder increases so very much more quickly, nearly as the sine, that the gain by this method is unappreciable until large angles are reached. Now the very alphabet of mechanics teaches us that a machine is a combination of appliances whereby we are enabled to perform work which with our unaided hands we could not attempt, and that it is more or less perfect as it performs exactly the work we require, or falls short of or exceeds that work. But however good the ordinary gear, it is evident that if it is made to have just the right amount of power to turn the rudder from 0 to 5 degrees, it will require five or six men at the wheel to move it from 40 to 45 degrees. Or again, if the

* Received 10th March, 1876.

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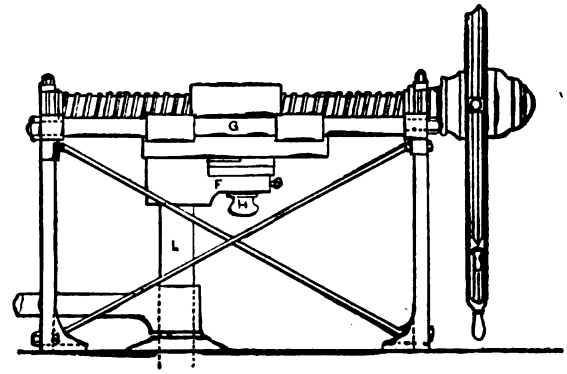
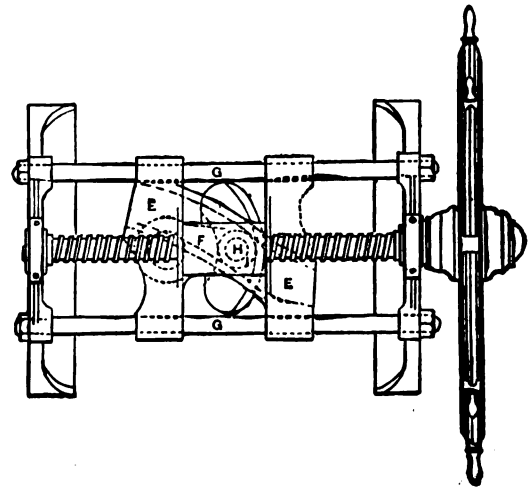
gear be made sufficiently powerful to enable one man to put the rudder hard over, it must be uselessly slow at the more central angles.

If the preceding conclusion be admitted, it follows that the only perfect steering gear is one in which the power brought to bear on the tiller increases in exact proportion to the pressure of the water on the rudder, and (although in small vessels this is not of much moment, for the gear may be powerful enough for the extreme angles and yet be decently fast at the more central ones) it becomes an important consideration in any vessel over 1,000 tons. This is no mere supposition. Every day we hear of collisions more or less disastrous; and in the majority of these cases if the whole helm could have been given either of the vessels the catastrophe might have been avoided, but before the steersman can summon assistance to put the helm hard over the mischief is done. Again, every large steamer now building and even some of the better class of river boats are being fitted with steam-steering gear, showing that the gear at present in use although all very well for plain sailing is useless in an emergency. In proof of this I may say—and I have no doubt but that similar instances have come under the notice of most present—that on the trial trip of a not very large steamer (some 1,800 tons) we could not get the rudder past 10 degrees even with four men at the wheel. Farther, I was told by a Clyde shipbuilder that on trying to turn one of their large steamers by hand gear they got the rudder over some 6 degrees, when on putting more men to the wheel they broke it.





I think enough has been said as to the advisability of making the means at every point adequate to the work to be performed in turning the rudder, and it remains only for me to describe this means. I am aware that the machine is not altogether perfect, but cost, compactness, and other items must be considered to a certain extent. As far as may be seen from a large scale model it works perfectly; but of course this is a very different test from a winter in the Atlantic.

In the diagram L is the rudder-stock on which is keyed the tiller F carrying at its outer end the pin H; on this pin is a brass or gun-metal roller I fitting the curved

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groove E E formed in the lower side of the travelling table, which is driven to and fro on the parallel guide rods G G by a screw turned by an ordinary steering wheel. When therefore the curved groove E E is driven directly fore and aft, the roller I and the pin H and with them the tiller F must accommodate themselves to the altered position of the groove by moving laterally, thus putting the rudder over to port or starboard. And the curve of the groove E E is so constructed, that supposing the resistance on the rudder, when at an angle of 20 degrees with the centre line of the ship, to be double what it is at 10 degrees, the travel of the table required to move the tiller one degree in the former position will be just double what was required in the latter; and consequently, as the same power—that is the steersman's effort—acts through double the distance, his power over the rudder at that particular angle is doubled, and similarly with all other angles.

It may be objected that the resistance on the rudder does not increase *exactly* as the sine of the angle to which it is put, but I have merely adopted this approximation in the meanwhile, until I can get authentic information as to the precise increase of pressure which takes place. I understand Mr. Froude has given this some attention, but I have been unable to find any account of his experiments in that direction.

As to the construction of the gear the sketch almost explains itself. The stands are of cast iron; the guides of malleable rod iron turned up true; they are screwed down at the ends a trifle smaller than the rest of the rod, so as to form a collar on which to heave up the nut. There are diagonal tie rods to prevent rocking, as the strain is not balanced as in the equal armed gear. The table and groove are of cast iron, and so made that along with the guide rods and screw they would form a kind of lattice girder, resisting any lateral kick of the tiller; the roller of gun-metal and pin of malleable iron (unless it seemed advisable to use steel). The gear can be instantly disconnected by withdrawing it.

The only objection I can see to this gear is that the roller I will be apt to wear, but as it is a very small part of the machine it could easily be renewed; in fact two or three spare rollers might be sold with each. However, inventors are notoriously the blindest of parents when the failings of their offspring have to be viewed, and it is more than likely there are faults in the construction which I have not observed, or have under-estimated, and which I shall be glad to have pointed out, as it is possible that they may be overcome.

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DISCUSSION.

Admiral J. H. SELWYN: I have no doubt whatever that, as a means of applying great power, the screw is one of the best, as it is the slowest; giving, therefore, the time that is gained by long leverage in another form; but I confess that my objections to all this kind of steering gear, which has been recently used, in consequence of other difficulties, is that it tends to throw a still greater strain on an already overburdened portion of the rudder. The head of the rudder can be twisted off; but you cannot always, at high speeds, force the rudder over. There is a great difficulty there. I think the object can be better effected by changing the form of rudder than by changing the steering gear; but the improvement in steering wheels, and the application to them of screws would be much greater if the constructors always considered the jolting motion caused by the intermittent beat of the screw on the ship. On the rudder there is a jarring jolt which transmits itself to any machinery employed in connection with the rudder head, and which makes it very difficult to preserve those surfaces in perfect order, so that on some occasions when it is most required the rudder will fail to act. I think that difficulty should be closely investigated by those who make gear for rudders.

Mr. WIMSHURT: In 1835 I built and fitted a vessel with a screw apparatus similar to that, and the difficulty there arose—as has been stated—from the jerking motion; and when it got to be a little loose the noise was very great indeed. We found it better to take away that machine, and put the common tiller ropes; but you must be aware, that with the sea running under the quarter, and the screw not only beating against it and catching as it generally does the broadest part of the rudder under the counter, the blow is very great; and if it is so rigid that there is no possibility of the rudder head moving, something must give way. Therefore I consider that screw machinery for steering is rather dangerous than otherwise.

Mr. J. SCOTT RUSSELL, F.R.S.: I am anxious—as there are many who have given their thoughts to this very important subject, especially at present with relation to war vessels—to have the opinion of one or two Members present on the principles which it is safe now to follow out in steering. Now, two modern improvements have been introduced, one of which has just been properly mentioned, namely, the introduction of the screw into steering apparatus. That is a very tempting system, because the screw has for that special purpose this great value, that you can get enormous power in very little space, without complexity of mechanism; therefore I think that has led so many people to adopt the screw. I wish to ask those gentlemen present who have studied this subject, whether it is or is not a disadvantage to the screw that it has so much power and so much friction that when it is struck it does not yield to the blow? I wish to ask you sailors whether you think it more desirable or more undesirable that there should be so much power in the mechanism that you can hold it fast in spite of the sea, or whether you do not think that a source of danger; and whether you would not rather that it was not so strong, and that the sea compelled you to let it go and yield? I know I have often, in steering a smaller class of ships, found that I saved mischief from being done by letting the wheel run away. Then the other point I wish to ask your opinion upon—as so many able men are here who have studied this subject—is, whether you like or dislike the terribly short levers which compactness and the force of this screw enables you to act with; and whether you do not prefer the rather clumsier longer levers of old-fashioned ships; and, in

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short, I wish to put you in this corner—I wish to ask you this question, whether you would not have a longer lever with a gentler screw, rather than the screw of this extremely short thread with an extremely short lever? You know that you would strain the stern-post much less. You know that, under the stern the concussions from the screw, which are very serious, would be less; and therefore I think it is most desirable just now that we should thoroughly understand how far we dare go in diminishing the lever and in increasing the strength of the screw and how far we should go back in the opposite direction. You will observe in this particular case an extremely short lever is used for the screw to act upon, bearing no comparison at all to the ordinary levers you would have to use. What does that say to you and me?—that there is at least four, six, or eight times more strain on the application on the rudder-head than there would be if that same screw had been applied to the outside of this long lever. I think these are most important points; and the gentlemen here should, if possible, say yes or no to those questions.

Admiral SELWYN: I may answer Mr. Scott Russell's question by saying that we should naturally prefer the longer levers, as giving us the greatest power applied to the best advantage, if it were not for the fact that they are almost impracticable in modern men-of-war, because we cannot afford the room for the sweep of such a thing as a tiller, though we manage sometimes to give the room necessary for a yoke, which is a double transverse tiller.

Mr. J. SCOTT RUSSELL: You could allow the room if it was over head under deck?

Admiral SELWYN: In some cases; but, even in those cases, we find that the danger of any rigid application of power—and it is not less in this case than in any other—is in throwing the men over the wheel. Men will stick to their wheel in a gale of wind, and they get thrown over and killed. That is not an infrequent accident; and I think if anything better of this kind could be devised—for I look at the employment of machinery as an advance over the old system—by a consideration that the female screw in which the male screw works need not necessarily be rigid, and that an elastic connection between the two—only yielding in certain ways to a certain extent on certain occasions—can be made, that would meet the greater part of the difficulty.

Mr. CHARLES LAMPORT: I have fitted a great many of these screws to my vessels, but I allowed on all occasions no less than 6 inches of play for the lash of the sea upon the rudder, by applying india-rubber to every one of the connections and joints. It was put in and required no care or attention; it was not one of those things which sailors' carelessness could possibly interfere with, but it met the objection of perfect rigidity.

Mr. HENRY LIGGINS: The author of the Paper says that his principle resists the lateral kick of the tiller. Mr. Russell has made some able remarks as to the desirability of that being accomplished. I will give some reasons why I think we should consider well before we adopt a rudder that is too rigid in resisting the lateral kick. I was crossing the Atlantic in the year 1863 with Captain Rivet, the present Commodore of the West India Mail Packet Service, in the very fine steamer the *Seine;* and either in 1861 or 1862 the *Seine*, in an outward winter voyage, was caught in a terrific hurricane in the English Channel, and for once in their long career the Royal Mail Company, or rather the Captain of their ship, felt it was his duty to seek a port of safety, and he run up either for Plymouth or Falmouth, I do not at this moment recollect which. When he approached the shore and got into the broken water, he found

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himself almost overwhelmed with the sea, and he is of opinion that for a moment he touched the ground from the excessive rise and fall of the sea. At any rate, he told us that two of the forward stanchions that support the spar-deck of that large ship were completely bent by the heavy body of water that came down on the forecastle deck; at the same time the ship plunged very heavily, and was struck in all directions by broken water. The wheel took command of the four men who were at it (it was a double wheel of course, being a large ship), pitched the men overboard, broke the arm of one man, and literally cut off the heads of two of the other men. Now, Gentlemen, I think that was a providential accident, for this reason—I believe if the tiller had not had lateral play, the probability is that the ship would have been lost with all hands; and that was the opinion of Captain Rivet at the time. It was a most pitiable and lamentable accident, but it would have been much more lamentable if the rigid tiller had caused the loss of the rudder-head, because the ship would then have been left without the means of steering. Under such circumstances, I need not point out to any seaman that she would have been in much greater jeopardy than she ever was; therefore, I think we should hesitate very much before we make anything too rigid in connection with steering gear. I will mention another reason why I think play is desirable. There was an occasion on which my daughter was on board a fine schooner yacht running up the channel off Beachy Head, and all of a sudden, when the men were at dinner, to their great surprise there was a cry of "The rudder is gone." It was one of the finest yachts in England, built by a most eminent yacht builder, and no expense had been spared; but from the particular form of the sea it so happened that the rudder-head was wrung off, and they were left on board a fast vessel running before a gale of wind in the most glorious style (and if everything had been all right, no doubt it would have been charming) without a rudder. That is a dangerous position in which to be put; therefore you cannot safely have a rudder too rigid. I could multiply those examples by many which have come in my way. I am sorry Mr. Reed is not here to-day, because I had the good fortune, some years ago, of being in his company on board the large schooner yacht *Livonia*, which I think had been sailing matches, but at any rate sailing at Barrow, and she had a screw steering apparatus of this kind, but with side lever arms. It was very unsatisfactory in its working, but it principally arose from what I believe to be the defect in most yachts, that of the raking stern-post, which made it impracticable to get the steering gear to work nicely with the wheel in an upright position. Mr. Reed said at the time he could not see his way to improve the steering apparatus in connection with that particular rudder, but practically we found it was always safer and better if we took off this wheel and steering apparatus and steered with the tiller; and, as a rule, we never ventured to sail matches in a heavy press of wind with the *Livonia* without taking off the wheel and using the tiller; therefore I think anything that is too rigid is attended with risk.

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CONCLUDING PROCEEDINGS.

The PRESIDENT: I am happy to say, Gentlemen, that we have had a very successful Meeting; and I am also glad that the last Paper to which we have just listened has excited so much interest. Nothing now remains for me to say except that this Annual Meeting is closed.

Mr. J. SCOTT RUSSELL, F.R.S.: I must object, my Lord, to your closing the Meeting without hearing a few words more from somebody. Brethren of the Craft—allow me to say, that, in closing this Meeting, we must remember to do all justice to the man who stands at the rudder. I say so because it is now, I think, the sixteenth or seventeenth time that we craftsmen have met in this room and discussed our professional measures, and for very nearly as long as that time we have been presided over by a nobleman who has occupied the highest positions in this country; and yet although he is a great statesman and a great politician, and I may even venture to say belongs to one party in the House rather than to another party in the House, he is above everything a lover of seamen, and sea folk, and sea craft,—and he comes here year after year to encourage us and keep us together, and make us go in that path which he thinks will be most useful to the public good. This year, as you knew from his opening speech, his great object was to see how he could help us in efforts jointly to better the naval marine of this country, and how he could make use of us best in our different crafts to advance the science of naval architecture with reference to purposes of war. I say, therefore, that we are infinitely obliged to the man who lays out our course, who lays down the duties of this Institution at these Meetings once a year, who presides over its Councils during our vacation, and who is good enough to come and take the rudder when we all meet together. Allow me to say he did us one other great benefit. I hope you will not forget he mainly moved in getting our profession educated, and laying the foundation of a complete system of education for naval constructors, so that gentlemen who visit us from outside may not be in a condition to say that we do not know our profession. And, lastly, his Lordship does more than that. His Lordship was at one time in such a position that he had to decide what sort of ships should be built for the Navy, and what sort should not be built; and I am happy to be able now to tell you that the ships which he said should be built for the Royal Navy at a critical moment have turned out all of them to be magnificent sea-going and sea-keeping vessels. On those grounds, I say, let us evince our high appreciation of the very great and continued kindness which for so many years our craft and profession have received at the hands of the gentleman who has been good enough to preside over our Meetings once more.

Mr. C. LAMPORT: Gentlemen, I consider it a high privilege to be allowed to second the Resolution which has been proposed by Mr. Scott Russell. He must be a clever man who following where Mr. Scott Russell has led can gather anything to say upon any subject upon which he brings his intellect to bear. There is, however, one point I may call your attention to, namely, this—that, whatever debt of gratitude we owe to his Lordship on this occasion, we must consider we have to add it to that which we owed on previous occasions and that our gratitude should have an accumulating force. At this Meeting, therefore, after so many others, we could not do less than give him, by acclamation, an accumulated vote of thanks. I think, before I sit down, I may call upon you to respond to the proposition made by Mr. Scott Russell in the most hearty manner you possibly can.

[The Resolution was then put to the Meeting, and carried unanimously.]

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The PRESIDENT: Mr. Scott Russell, Mr. Lamport, and Gentlemen,—Both my honourable friends who have been so good as to move and second this vote of thanks, have expressed themselves in terms which I fear are very much beyond anything I have deserved. The only merit I can claim in this room is that—as Mr. Scott Russell has truly said—almost from the beginning of this Institution I have been its President. In the second year of its existence this Institution did me the honour to elect me to that office, which position I have held ever since; and it has been truly gratifying to me to observe, from year to year, the increasing success, and more than success—the increasing public value and utility—which I think this Institution may fairly claim. So long as I can promote its value and utility, and so long as I have the honour of being your President, I shall be happy to render you any service in my power; and I thank you all most sincerely for the cordial manner in which you have honoured me to-day by this vote. But now, Gentlemen, some words of thanks are really and honestly due to the ability with which the important duties of Secretary of this Institution have been discharged by my friend, Mr. Woolley. We none of us have forgotten the value we attached, and justly and properly attached to the assistance we received from our friend Mr. Merrifield. We all were very sorry when Mr. Merrifield found he was compelled to resign the position so long held by him; but we are happy now to find that we were very fortunate in the choice of a successor; and I am glad to say—and to make this public acknowledgment of my sincere opinion—that in Mr. Woolley we have had the good fortune to find a successor quite worthy to follow in the steps of Mr. Merrifield. Therefore, our thanks are really and fairly due to Mr. Woolley, and I hope he will long continue to fill with equal credit and honour the position of Secretary.

Mr. WARREN: My Lord and Gentlemen, I am called upon to perform a very pleasing duty. It is to propose a vote of thanks to the Vice-Presidents, Members of Council, and the Officers of this Institute. The vote of thanks which the President has so kindly proposed to Mr. Woolley is embraced in my proposition, and I am sure will receive cordial support. Knowing so many of the Officers of this Institution as I have done intimately for so many years, I can speak positively as to the great good that has resulted from the labours of these gentlemen; and esteeming them so highly as I do, I am sure you will not deem it out of place if I offer one or two observations. It is always pleasing to Members of an Institution of this kind to find themselves recognised in any action taken by the Institution. I am sure that everything has been done by the President and Officers of the Institution for the good of the Institution, and with that object solely in view; but I find there is a rule which says that the Members may be called together at any time; now I am not aware of any Meeting having been called during the whole time the Institution has been in existence, except the annual one: on several occasions Papers have been presented to the Board of Trade, or to the Government in various ways, which have emanated from the Council; and I have not the slightest doubt that the very best thing has been sought to be done. But may I ask, with all kindness—I place it before the President and the Members of Council for consideration—whether it would not be just as well occasionally to take the Members of the Institution into their confidence, and when any question is thought of sufficient importance to make communications to Government Departments thereon, to call a Meeting of the Members at which their opinions could be presented. There is also another thing I may mention. The offices of Vice-President and Members of Council are esteemed and honoured, and justly so. Of course it is within the recollection of all of us that many of these are honorarily conferred on men of very eminent ability; but who from their great age, and one thing and another, are practically non-existent so far as the Institution is concerned. I think that of the whole number of Vice-Presidents you will find only six naval architects who take any active part in the Institution,

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and of Members of Council you will find about six active Members only. Of course, many of our Officers hold appointments in all parts of the country away from London. I would, therefore, suggest to the Council for them to deal with it as they think proper, whether it would not be advisable to infuse a little more blood into the Council. The Vice-Presidents I do not speak of; that is a thing of less importance. There is also another suggestion—whether it would not be advisable once a year, or at some other time, when anything of particular importance is being brought forward, that the Members as a body should be consulted before any recommendation is made to a Government Department? I am not making it a personal question; I simply want to say we all feel such an interest in the Institution that we as Members would like to take a little more active part in what is done. I beg to propose a vote of thanks to the Vice-President, Members of Council, and Officers of the Institution.

Mr. W. DENNY: I have much pleasure in seconding this Resolution. Although we find that, perhaps, the largest number of the Council do no work, still I think, from the way the Meetings are conducted, that the portion of the Council who do work, work well. We are very happy in having both working and honorary Members of Council. I have much pleasure in seconding the vote of thanks. Perhaps I might add that the suggestion of consulting the Members might be carried out by issuing circulars or special letters, which could easily be done without much trouble.

The PRESIDENT: Gentlemen, it becomes my duty, as I am not myself involved in this motion, to put to the Meeting the Resolution which has been proposed. In doing so, I beg to refer, in one word, to what has fallen from Mr. Warren; and to say, that for myself, during the many years I have had the honour of acting as your President, my object has always been that we should work together as harmoniously as possible to promote the objects we have in view. I think it is due to Mr. Warren I should say, on my own part, that what has fallen from him is well worthy of our consideration.

[The Resolution was then put to the Meeting, and carried unanimously.]

Mr. A. SEDGWICK WOOLLEY (Secretary): My Lord and Gentlemen,—Really the praise which Lord Hampton has given me for the little work I have been able to do has been quite unexpected on my part. I have only worked as well as I could for the sake of the Institution, as I always hope to do. But it would not have been the slightest use my working at all if I had not received a great deal of kindness and assistance from the Members of the Institution; and I hope, in the future, I shall always receive as much kindness from them as I have on the present occasion, and then my task will be really a very light and pleasant one.

Mr. MARTELL: My Lord and Gentlemen,—I beg to propose that the thanks of this Institution be presented to the Society of Arts for their usual kindness in placing this beautiful Hall at our disposal. I have the more pleasure in doing this, because we take it for granted that we can come to this Hall; and unless such a vote is recorded, and brought to our recollection, the great kindness that we receive from the Society of Arts in placing this Hall at our service might pass unrecognised. I scarcely know what we should do without some such place as this in which to hold our Meetings.

Mr. BARNES: I have much pleasure in seconding the Resolution.

The PRESIDENT: Gentlemen, I need not formally put this motion for a vote of thanks to the Society of Arts. We are, of course, all of us very much indebted to them for the kind and liberal manner in which, year after year, they allow us to hold our Meetings here. It only remains for me to express the hope that we may all meet here again next year.

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MEMOIR OF THE LATE SIR BALDWIN WAKE WALKER, BART., K.C.B.,

Honorary Associate of the Institution of Naval Architects.

Sir Baldwin Wake Walker, eldest son of the late Mr. John Walker, entered the Navy in 1812, and was made a Lieutenant in April, 1820, when he was appointed to the *Nautilus*, on the Jamaica Station. He returned to England about the commencement of 1822, and the following year was appointed to the *Brazen*, in South America, where she remained until 1826 when she was ordered to the coast of Africa. In 1828 Lieutenant Walker served in the *Rattlesnake* and *Ætna*, both on the Mediterranean Station. While serving in the latter vessel he distinguished himself by the valuable assistance he rendered to Captain Lushington, who commanded the *Ætna*, in October, 1828, at the taking of Morea Castle and Patras, the last hold of the Turks in the Peloponnesus. His services on this occasion were mentioned in the *Gazette*, and he was created a Knight of the Legion of Honour of France, and of the Redeemer of Greece. He continued on the Mediterranean Station until 1834, in the July of which year he was promoted to be Commander, and afterwards served from September, 1836, to November, 1838, on board the *Vanguard*.

For some time Captain Walker was a Rear and Vice-Admiral in the Turkish Service, and for the conduct he displayed in the command of the Ottoman naval forces during the operations on the coast of Syria, including the attack upon Beyrout (where his zealous, persevering and active exertions were warmly praised by Admiral Sir Robert Stopford), and at the bombardment of St. Jean d'Acre, he was nominated an Honorary Knight Commander of the Order of the Bath in January, 1841, and was made a Knight also of the Iron Crown of Austria (2nd class), St. Anne of Russia (2nd class), and of the Red Eagle of Prussia. He afterwards served in the *Queen*, bearing the flag of Sir John West, at Devonport, and in the *Constance* in the Pacific. In 1848 he was appointed Surveyor of the Navy, and for some time, until he obtained his flag, was one of the Naval Aides-de-camp to the Queen. He resigned his office as Surveyor of the Navy in January, 1861, and was appointed the following month Commander-in-Chief at the Cape of Good Hope. Since then he had not been employed, as he was placed on the Retired List of Admirals in 1870. For his services during the Russian war he was in 1856 created a Baronet.

In 1861 the distinction of "Honorary Associate" of the Institution was unanimously conferred upon him.

He died on the 12th February, 1876, aged seventy-three years.

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MEMOIR OF THE LATE THOMAS LLOYD, C.B.,

Vice-President of the Institution of Naval Architects.

It is with much regret that we have to record the death of one of the original Vice-Presidents of the Institution, Mr. Thomas Lloyd, C.B., whose name is associated with the rise of the marine engine in the Royal Navy since its first introduction. Born at Portsea on the 29th October, 1803, and educated privately in that town, he successfully passed the competitive examination for the School of Naval Architecture which then existed under Dr. Inman in Portsmouth Dockyard, on the 1st of June, 1819, where he remained until the 1st of January, 1826, when he was appointed a supernumerary officer at Plymouth Dockyard. In 1830 he was transferred to the Designers' Department of the Navy Office, and after having made a six months' cruise in the *Columbine* he was chosen in the following year to go through a course of study in steam and machinery, and with that view he was appointed Superintendent of the Wood Mills and Block-making Machinery in Portsmouth Dockyard. In 1833 he became Inspector of Steam Machinery at Woolwich, and two years later he was appointed Assistant to Mr. Peter Ewart, who was at that time created Chief Engineer and Inspector of Machinery. He continued to hold that office until 1842, during which time his duties entailed upon him the periodical survey of the machinery of all the Mail Packets, as well as visits to many of the large Engineering Works in the United Kingdom, on which he had to report to the Admiralty. In 1842, on the death of Mr. Ewart, Mr. Lloyd succeeded him as Chief Engineer and Inspector of Machinery, and he remained at Woolwich in that position until 1847. It was during this time that the question of the relative merits of paddle-wheels and screw-propellers became a matter of so much controversy, and in his position as Chief Engineer at Woolwich Mr. Lloyd was called upon to conduct the investigations and experiments which were instituted by the Admiralty to determine the question, the result of which led to the general abandonment of paddle-wheels for ships of war, and the introduction of the screw propulsion instead. The screw was however for a long time merely employed as an auxiliary in men-of-war, and it was not until 1851 that the French Government determined to build a line-of-battle ship to carry high-power engines so as to obtain a high speed. Mr. Lloyd, who had in 1847 gone to the Admiralty as Chief Engineer of the Navy, had the opportunity of making an early inspection of this experiment on the part of the French Government; for at the close of

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the Exhibition of 1851 he in company with Mr. Watts the Chief Constructor of the Navy, Sir Joseph Whitworth and Mr. John Penn, obtained permission to visit the French Arsenals.

The success of the *Napoléon*, the vessel with which this experiment was made, determined our own Government to build the *Agamemnon*, which in conjunction with the United States frigate *Niagara* so successfully accomplished the laying of the first Atlantic Cable in 1858. At the request of the Atlantic Telegraph Company Mr. Lloyd co-operated with Mr. Penn and the late Mr. Joshua Field in superintending the arrangement of the machinery for paying out the cable.

In 1856, at the commencement of the Crimean War, Mr. Lloyd accompanied Sir Baldwin Wake Walker and Mr. Watts to France to witness the experiments made by the late Emperor of the French on the efficacy of protecting ships' sides by means of shot placed in an external wooden case, and it was at Mr. Lloyd's suggestion that this idea was abandoned in favour of solid armour plates.

In 1868 Mr. Lloyd was created a Companion of the Bath, and in the following year he retired from the service. The following is the recommendation addressed by Sir Spencer Robinson to the Treasury:—

"To state that Mr. Lloyd has discharged his duties with diligence and fidelity, and "entirely to my satisfaction, would be but a feeble expression of my opinion of his "deserts.

"Not only has Mr. Lloyd so discharged his duties as to entitle him to such an "acknowledgment, but there is no public servant within my knowledge who has so "largely contributed to the advance of practical science in his particular department.

"To Mr. Lloyd, more than to anyone else, is due the successful application of the "screw to the propulsion of steam ships; and it was owing to his enlightened knowledge "and his zealous exertions that the Royal Navy was enabled to take the lead in its "application to ships of war.

"During a very long public life Mr. Lloyd has been distinguished for wise and "carefully-considered suggestions for the improvement of the details of marine engines; "and I venture to say that the principal marine engine makers in the kingdom have "frequently consulted him, and always benefited by his advice.

"I do not hesitate to recommend Mr. Lloyd's case as one most specially deserving "the greatest amount of consideration which it is in the power of the Treasury to "bestow.

(*Signed*) "R. SPENCER ROBINSON,
"*Controller of the Navy.*"

Mr. Lloyd died of an apoplectic seizure on the 23rd March, 1875.

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MEMOIR OF THE LATE MR. JOSEPH LARGE,

Vice-President of the Institution of Naval Architects.

Mr. Large entered the School of Naval Architecture at Portsmouth, on the 18th September, 1822, where he remained till September 18th, 1829, when he was appointed a supernumerary officer at Sheerness Dockyard. Next year, on the 21st March, 1830, he was transferred to Chatham, but on the 13th of August, 1833, he returned to Sheerness, where, on 11th April, 1834, he was promoted to be Acting Foreman, which office he retained till the 4th December, 1837, when he was promoted to Woolwich as Foreman. By the order of the Lords Commissioners of the Admiralty he was directed, on the 11th April, 1847, to proceed to Portsmouth to act as Secretary to the Committee of Reference, which was a Committee appointed, with Dr. Inman as Chairman, to inquire into the state of designs of vessels; in consequence of whose report the *Cæsar* 90-gun screw, the *Barracouta* paddle-wheel steamer, and several other vessels were built. He again returned to Sheerness to act as Assistant Master Shipwright, on the 16th June, 1849, to which post he was promoted after passing a competitive examination, and continued there till the 7th November, 1853, when he was sent as Assistant Master Shipwright to Woolwich Dockyard. On the 12th May, 1858, he was promoted to the Admiralty as Assistant Surveyor, a title which was afterwards changed to that of Constructor of the Navy. He held that appointment until 1864, when, on the 22nd of June of that year, he retired from the Service on a pension.

Mr. Large was elected a Vice-President of the Institution in the year 1861, and was well known and respected in the profession for his general ability and sound knowledge of the intricate problems connected with naval architecture.

He died on the 21st May, 1875.

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MEMOIR OF THE LATE MR. EVAN LEIGH,

Associate of the Institution of Naval Architects.

Mr. Evan Leigh was born at Ashton-under-Lyne, and was the son of the late Mr. Peter Leigh, a cotton spinner, of that town. When eighteen years of age he undertook the management of his father's mill. The intricacies of the cotton machinery seem to have been congenial to the proclivities of the young man, who soon tried experiments with new combinations and adaptations; for, at the early age of twenty-one, he effected one of the most striking improvements, *viz.*, the coupling of hand mules and the "putting-up" motion, which wrought a speedy and complete revolution in hand-mule spinning, and reduced the price of spinning to about *one half.*

Mr. Leigh was the first to practically connect carding engines together. In the year 1835 he connected a number together in a mill at Macclesfield. The slivers from each card were deposited on a railway, which conveyed them to a lap-head. In America this system is now almost in general use.

In 1850 he introduced several great improvements in cotton machinery; amongst which may be mentioned a patent for his well-known "Self-stripping Revolving Flat "Carding Engine" and an improved "Derby Doubler." The former he has since at various times considerably improved, having given particular attention to carding cotton; and at the time of his death was engaged with one of his sons, Mr. E. A. Leigh, in completing some great improvements in the carding engine. The improvements in the "Derby Doubler" consisted in adding a taper table to an ordinary lap machine. This table had a pair of callender rollers down each side. These rollers drew the ends from a number of cotton cans, placed in rows; and a metal conductor for each end, being placed behind the callender rollers, deposited the ends neatly side by side as they passed along the table and through the lap machine at the broad end. This machine has not been improved upon to this day.

It was about this time that Mr. Leigh retired from the cotton manufacture, and commenced business as a machine maker at Collyhurst Mill, Manchester, owing to the difficulty he experienced in getting machinists to adopt his inventions.

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He was very successful in the manufacture of his patents; so much so that, during the time of the American War, he constructed and started the extensive and splendid machine works at Miles Platting, now known under the name of "Evan Leigh, Son "and Co. (Limited)." The conversion of the concern into a limited company resulted in a heavy loss to Mr. Leigh, so that in 1869 his connection with it entirely ceased.

After a year's unsuccessful experiments, upon which a considerable sum of money was expended, in 1857 he patented the "Loose Boss-Top Roller," now universally used in nearly all cotton mills. This invention proved a most lucrative one. The "Loose "Boss-Top Roller," when properly constructed, effects a considerable saving both in oil and leather, and in the better working of the frames. It also saves power and makes more regular yarn, and requires for lubrication but about 5 per cent. of the oil that is necessary for the ordinary roller.

In connection with textile machinery he also took out patents for improvements in slubbing and roving frames, paper tubes, throstles, the use of cast iron for spindles, cotton gins, preparing and spinning flax, wool, silk waste, &c.

In 1871 Mr. Leigh published a work, in which, as he stated in the preface, he gave the results of nearly half a century of practical experience of mills and mill machinery. It was published in two large volumes, containing forty plates and two hundred and fifty-nine other illustrations, under the title of *The Science of Modern Cotton Spinning.* This work is one of great authority, and is said to be the best work that has yet appeared on the subject. Much of this book was written after midnight, when the day's work was done.

Mr. Leigh held an eminent position in connection with mechanical science and engineering, and his inventions have added appreciably to the list of achievements in that department which has illustrated our time.

As the inventor of the "Twin Screw" for steam ships, which has now been extensively adopted both in the mercantile service and in the British and Foreign fleets, Mr. Leigh will be remembered as an important contributor to naval architecture. The following note on this subject is extracted verbatim from one of the many papers and pamphlets relating to mechanical works Mr. Leigh had from time to time put forth:—

"In the year 1849 I took out a patent (No. 12,708, dated July 18th) for steering "ships, by having separate power to each propeller, being twin screws or detached "paddles, with the object of turning a vessel more readily out of its course in time of "danger, by reversing one paddle or other propeller, and steering generally by giving "more or less steam to one engine or pair of engines. Notwithstanding the common

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" sense of this arrangement, by which all the power on board could be employed in " cases of emergency to avoid collisions, &c., I could neither get the Government of the " day or any of the shipbuilders to take it up; but I must admit that I received a letter " from the Lords of the Admiralty thanking me for the communication, but nothing " more."

Since that time, however, the "Twin Screw" has come into general use, as already stated.

In 1861 he first conceived the idea of conveying railway trains across the Straits of Dover, and took out a patent for it, connected with some other nautical matters; and in the following year he exhibited his patent ship in London to the Lords of the Admiralty. In 1867 he patented a plan for shipping and unshipping the trains. He took very great interest in this subject.

Mr. Leigh laboured hard, in conjunction with the late Sir William Fairbairn and others, on the Manchester Patent Right Defence Association. He advocated cheap patents, and more facility for obtaining them.

He was the President of the Scientific and Mechanical Society of Manchester, and Associate of the Institution of Naval Architects, before which he read Papers on " A Plan for Conveying Railway Trains across the Straits of Dover," and on " The " Steering of Ships." He was an Associate of the Institution of Civil Engineers, a Member of the Institution of Mechanical Engineers, a Member of the Society of Arts, and of various other Institutions.

Mr. Leigh died from heart disease, brought on through chronic bronchitis, on the 2nd of February last, at his residence, Clarence House, Manchester; and his loss will be widely regretted, not only as a man of science, but for his amiable disposition and for the unostentatious benevolence with which he engaged in works of charity.

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To illustrate Mr Goulaeff's Paper on Circular Ironclads.

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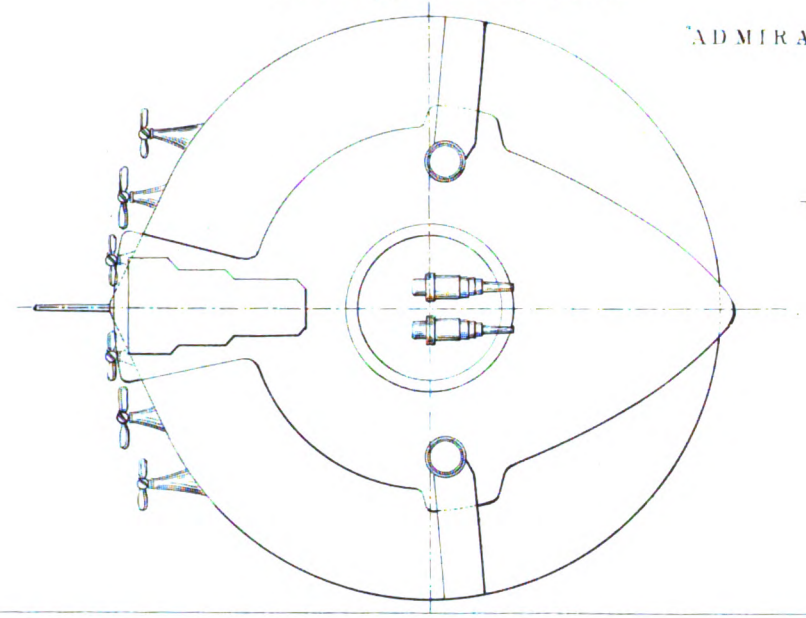

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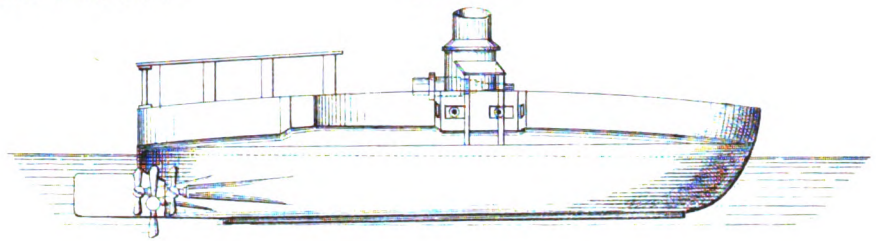

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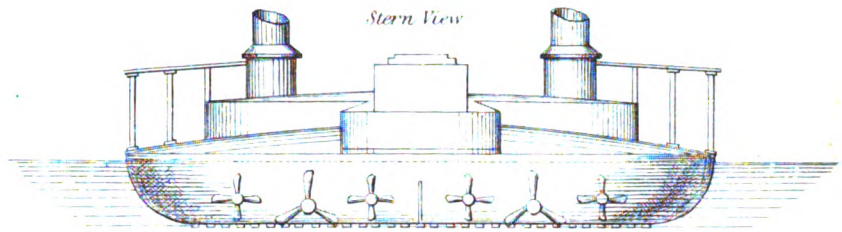

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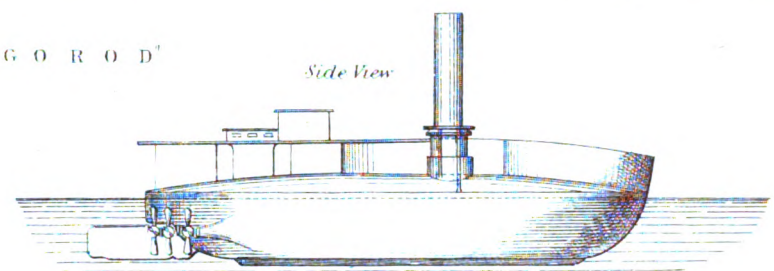

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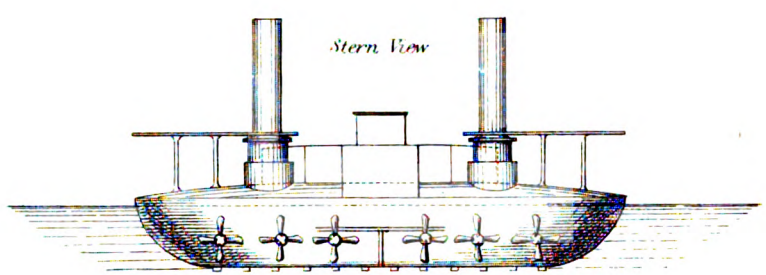

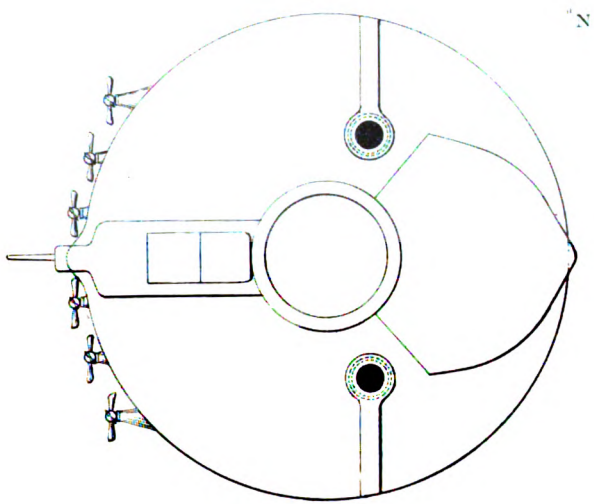

Plan of Upper Deck Breastwork

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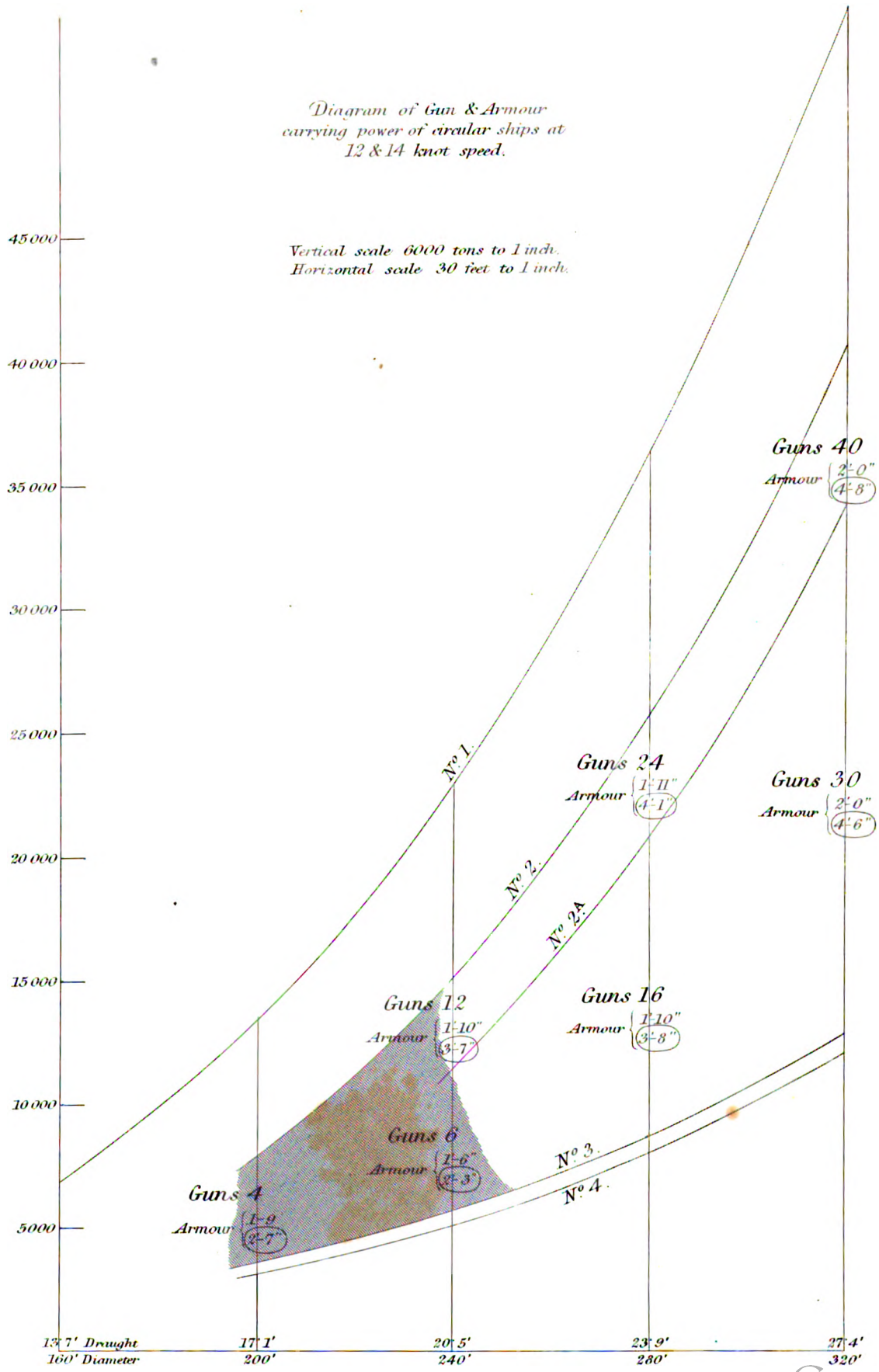

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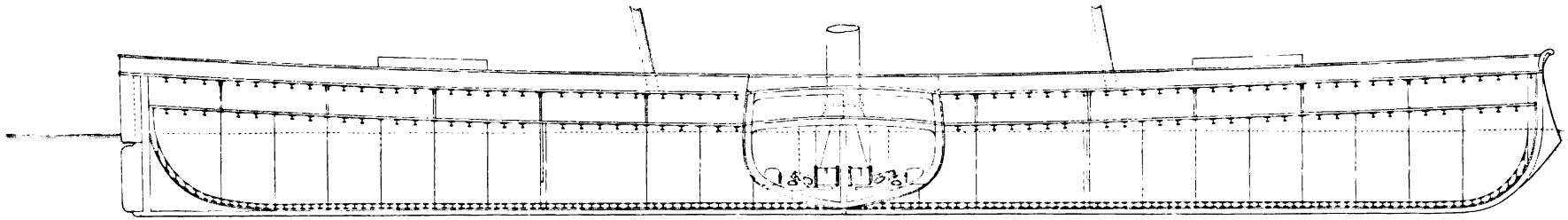

Composite Cellular War Ship.

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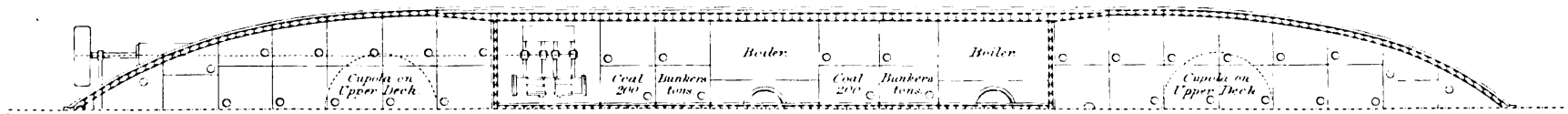
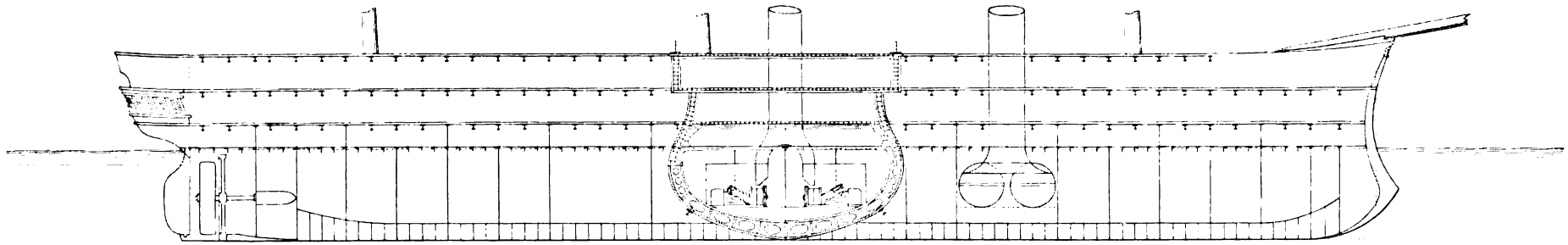
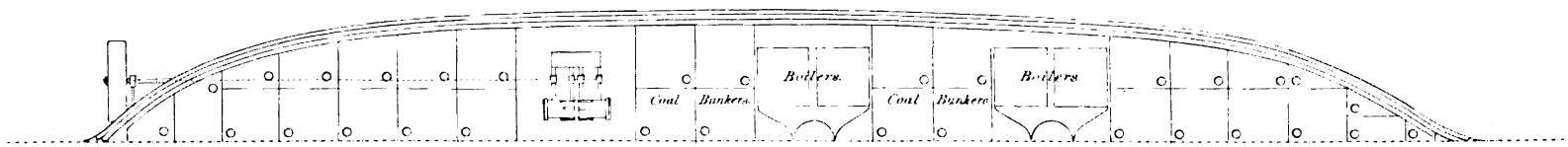




"Vanguard" fitted with the Cellular Principle.

5 10 20 30 40 50 60 Feet.



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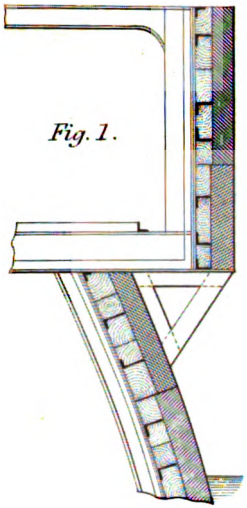

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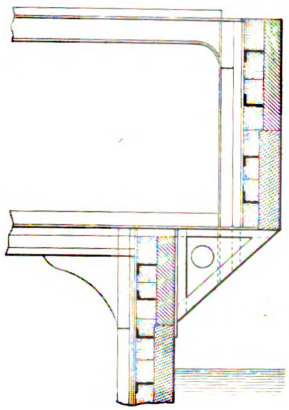

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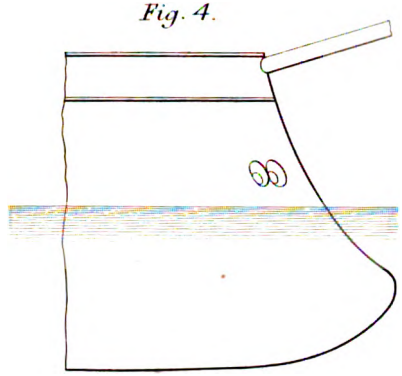

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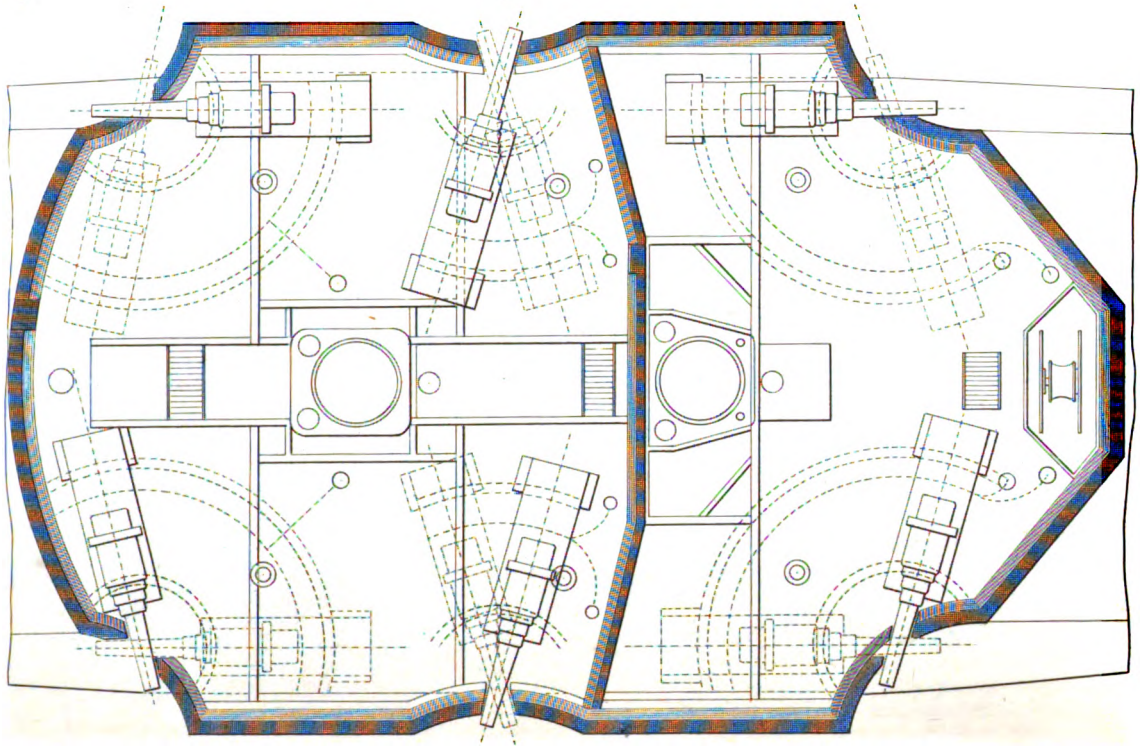

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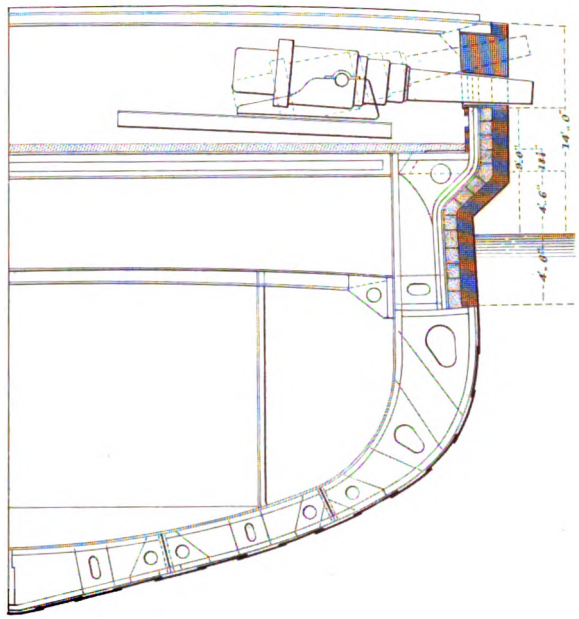

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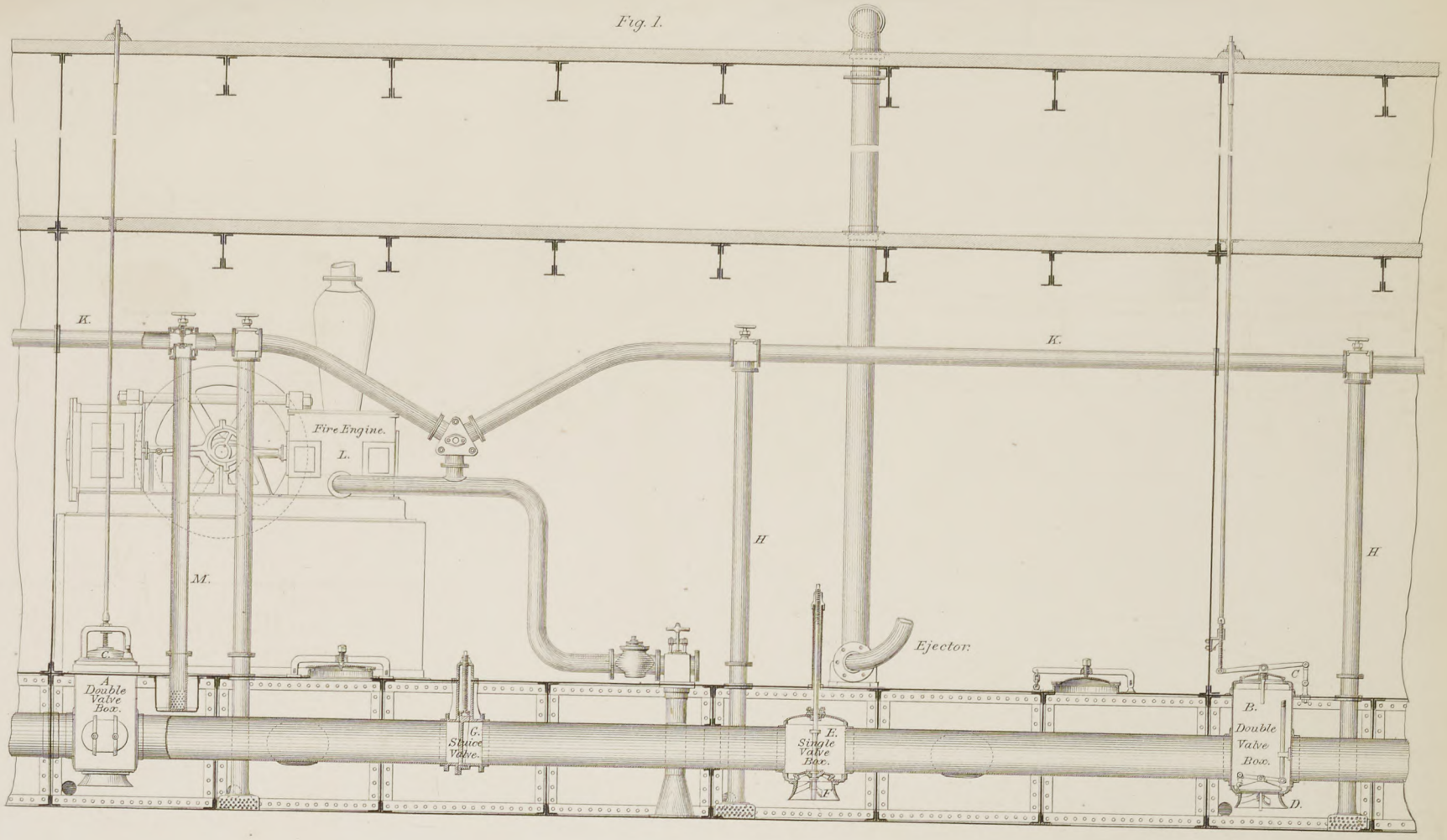

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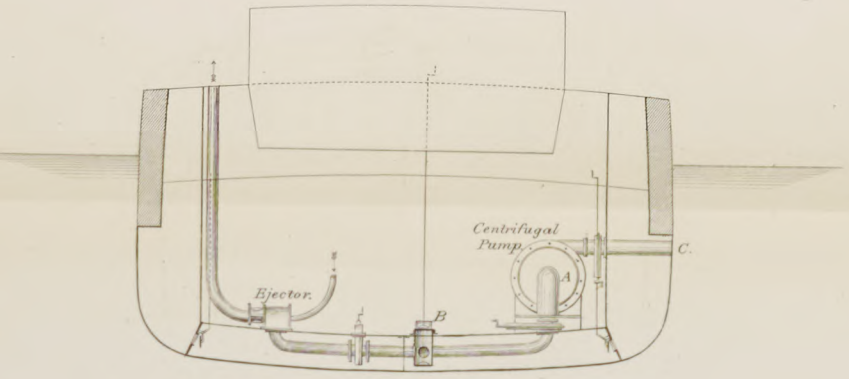

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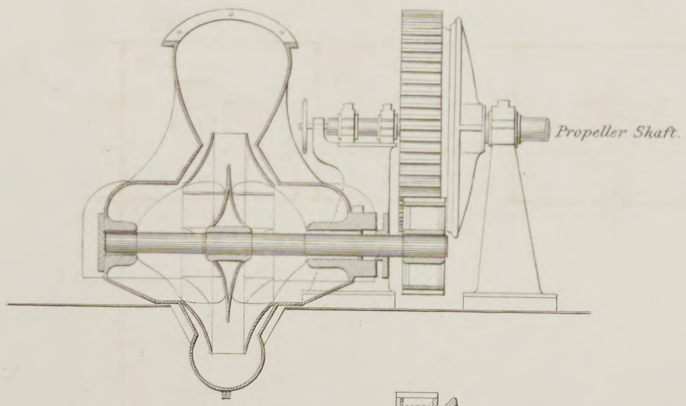

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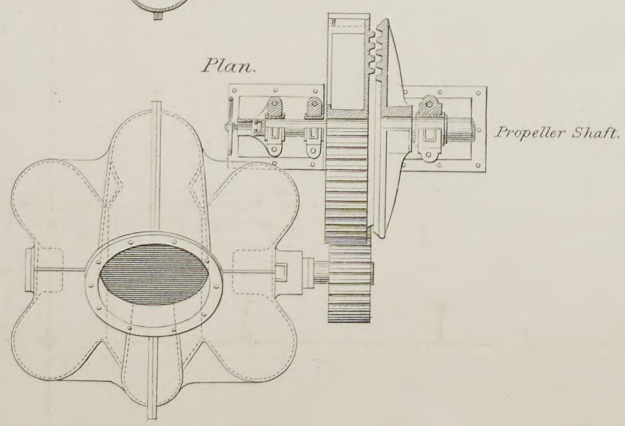

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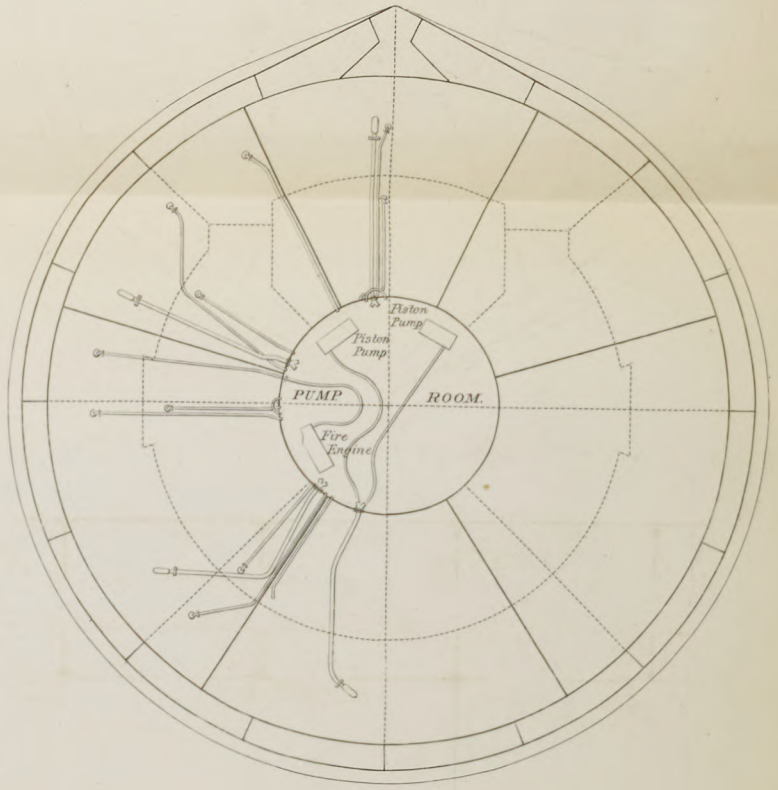

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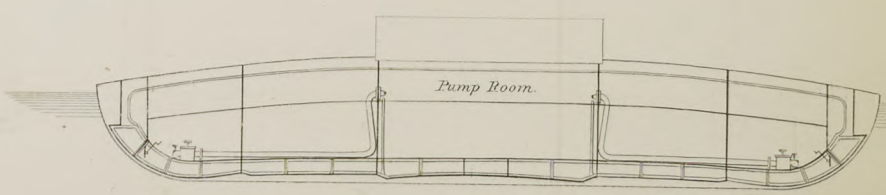

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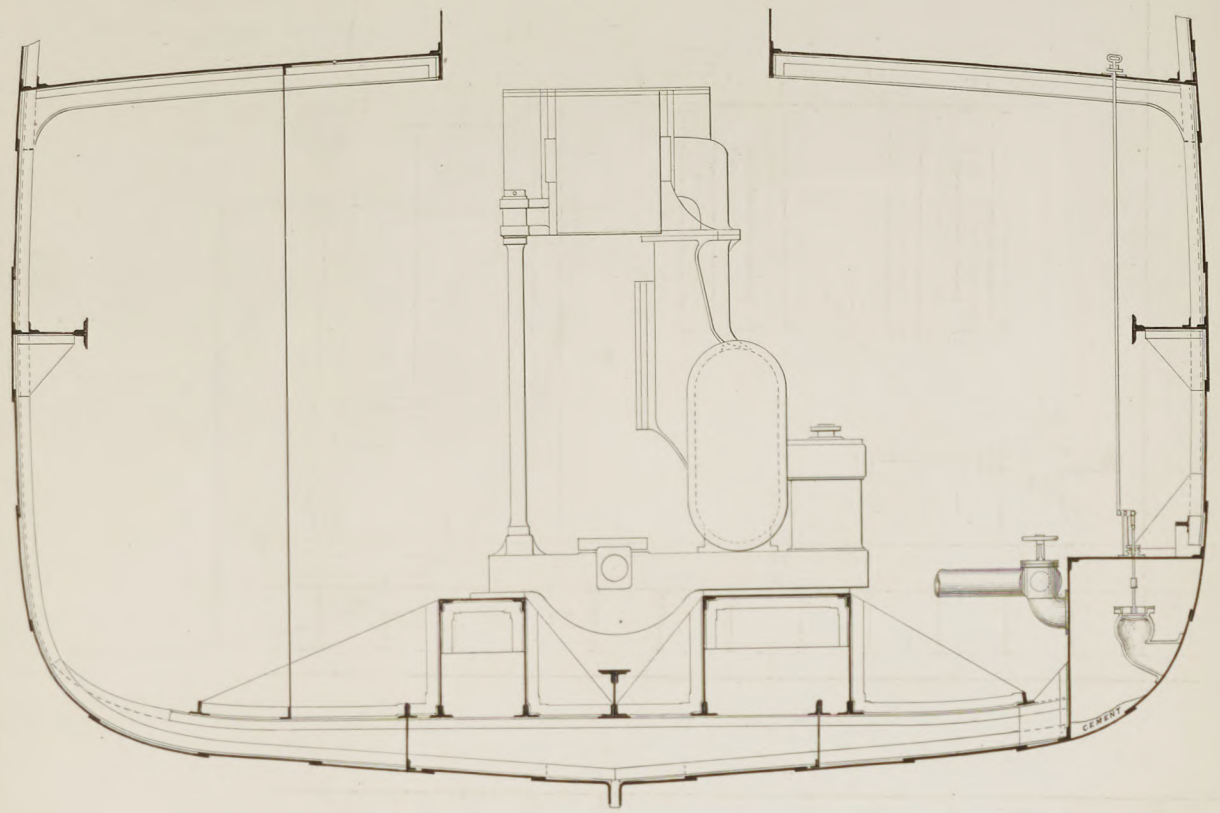
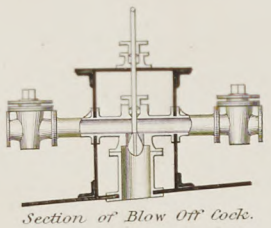
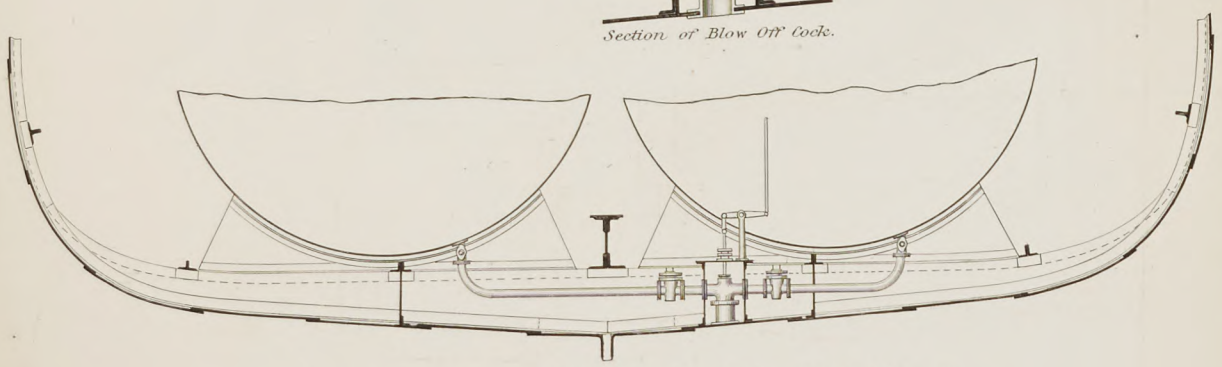
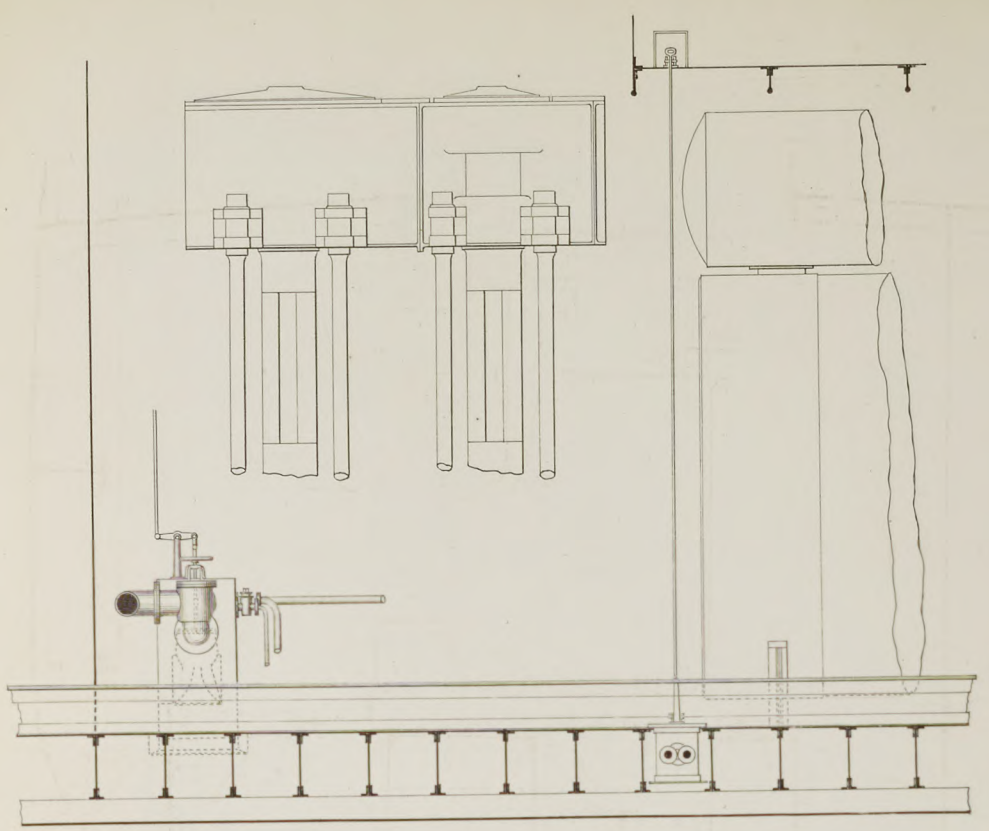


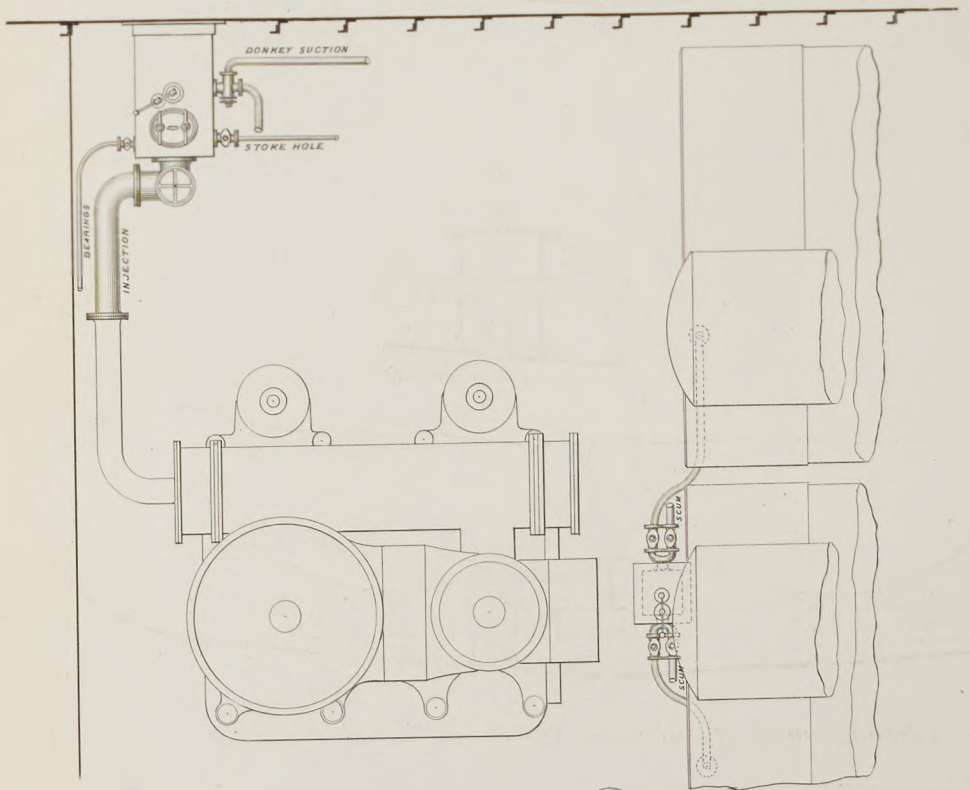


Section of Blow Off Cock.



Arrangement of Valves as fitted in "S.S. Helios."





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To illustrate Mr. H.G. Spence's Paper on Accidents to Sea Cocks.

Valves as fitted in the "J.B. Eminson."

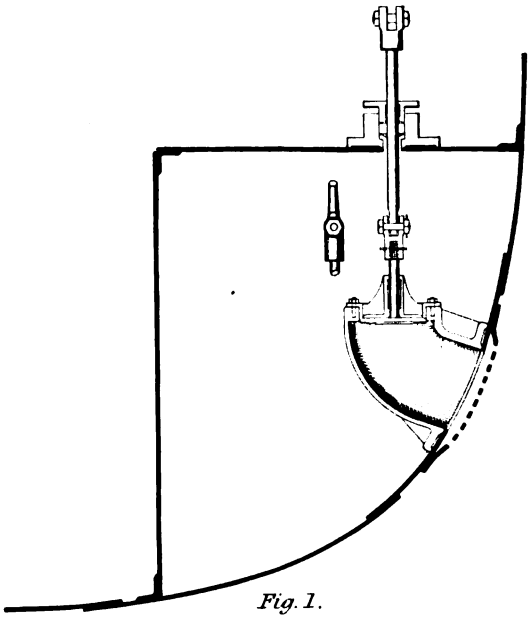

Fig. 1.

Proposed Valve for Blow Off Cocks.

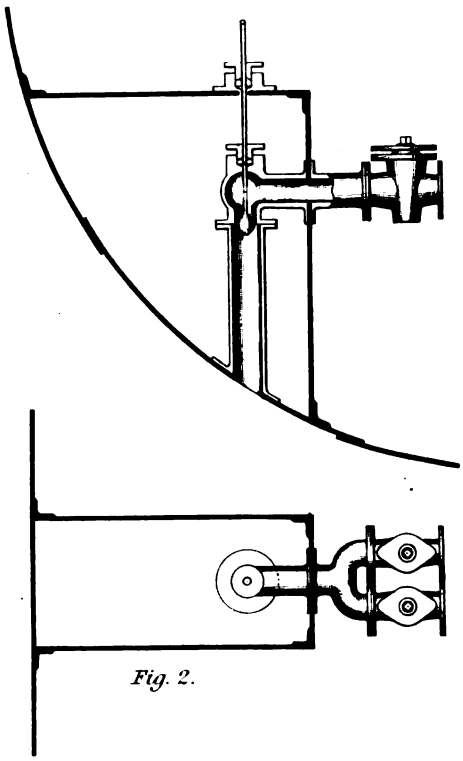

Fig. 2.

Handle on Deck for Valve.

Valve Open *Valve Shut*

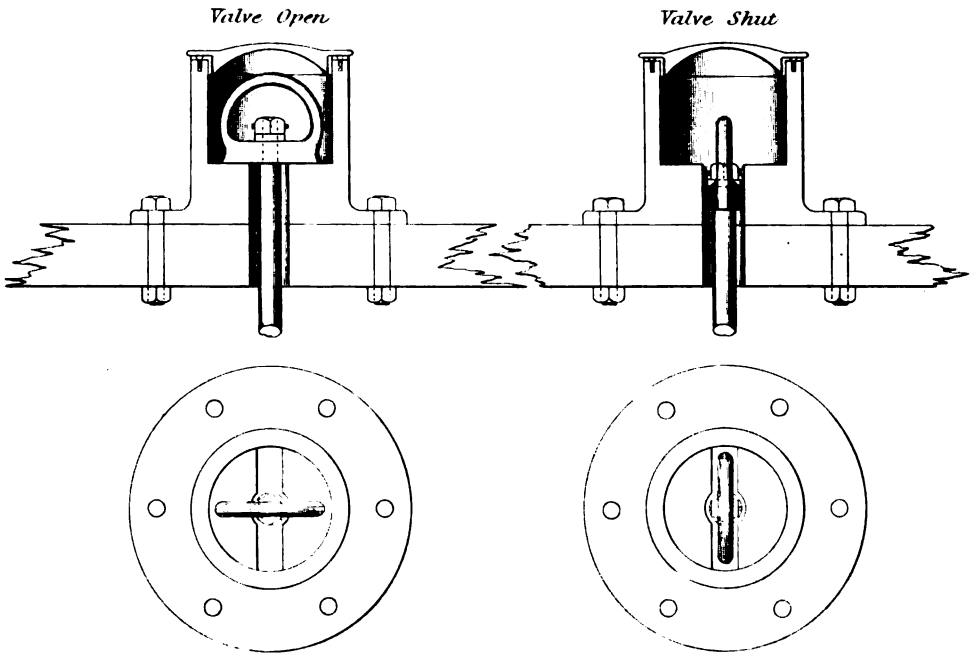

Fig. 3. Fig. 4.

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To illustrate Mr. Latimer Clark's Paper on the Nicolaieff Floating and Depositing Dock.

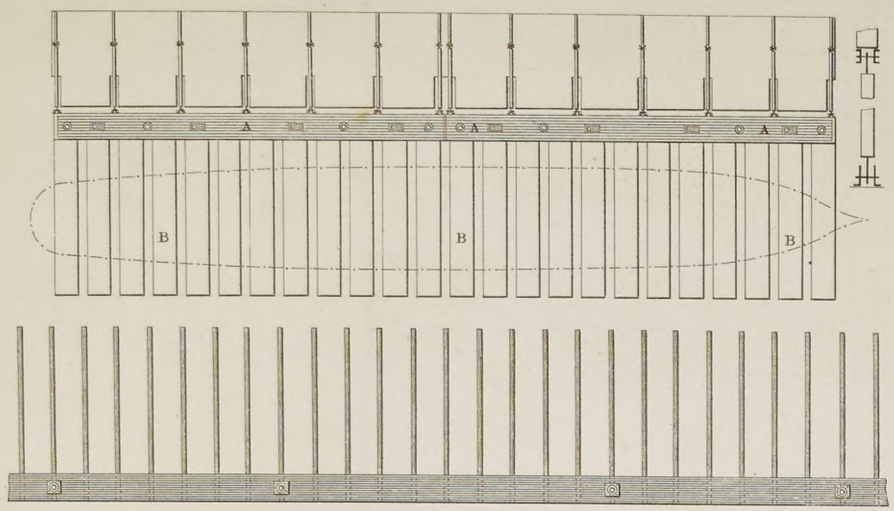

Fig. 1.

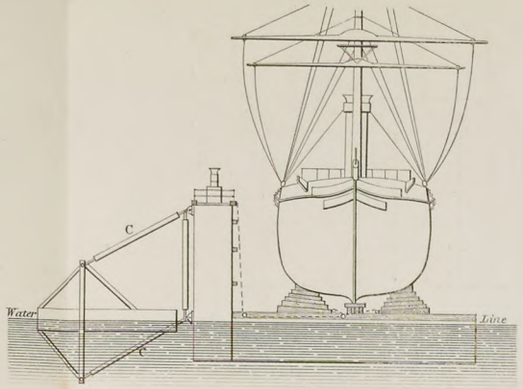

Fig. 2.

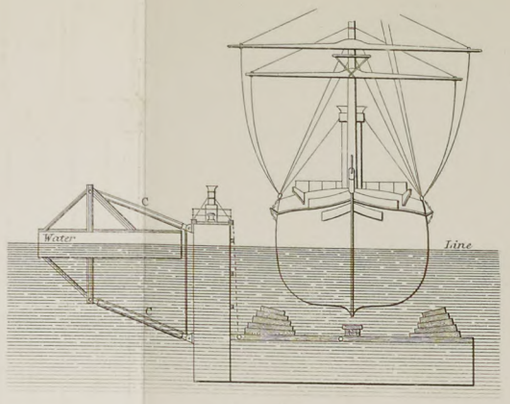

Fig. 3.

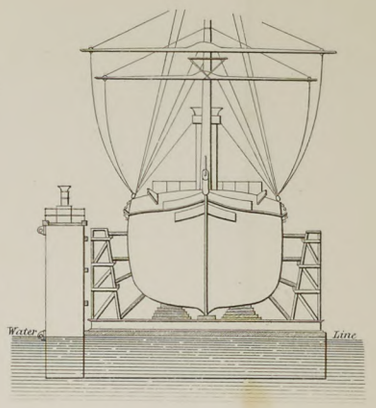

Fig. 4.

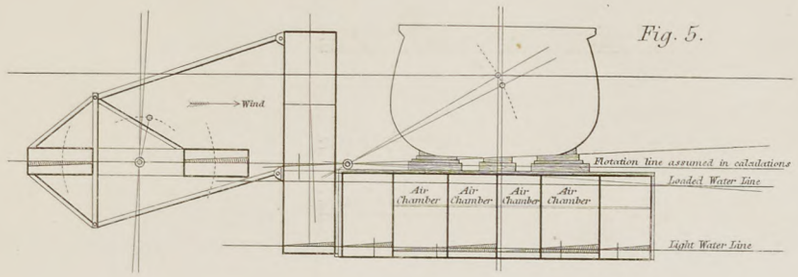

Fig. 5.

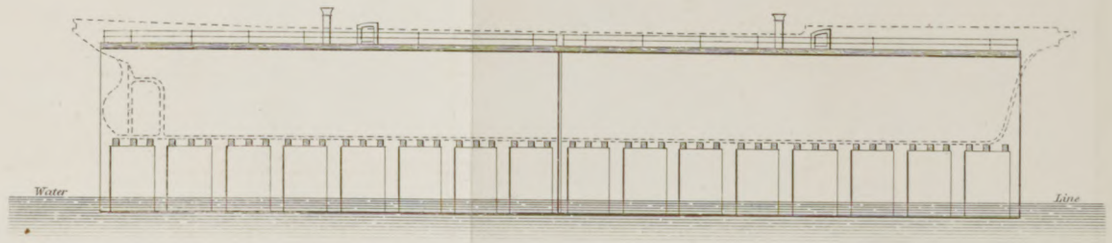

Fig. 6.

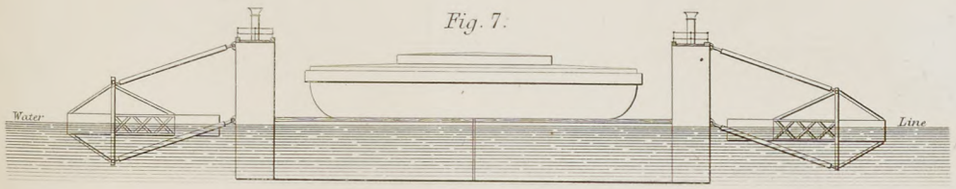

Fig. 7.

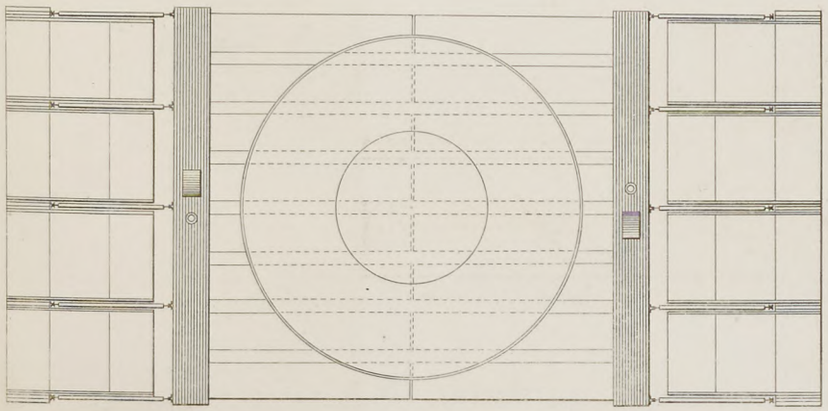

Fig. 8.

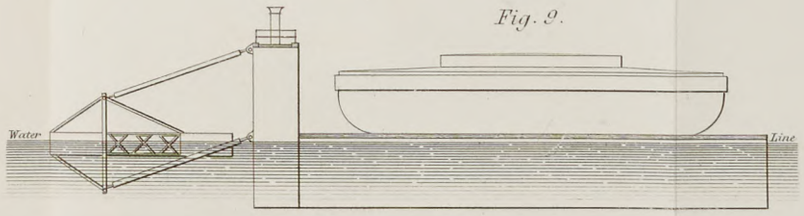

Fig. 9.

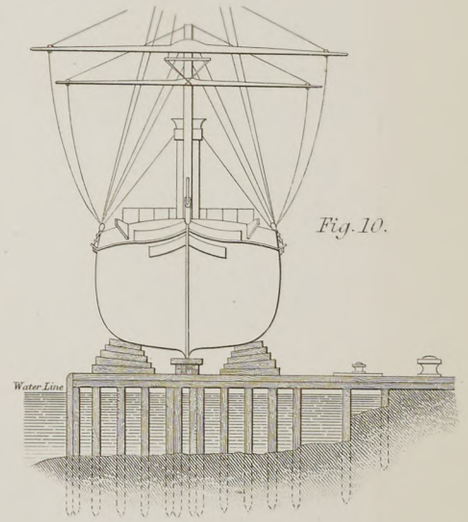

Fig. 10.

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To illustrate Mr. W. Froude's Paper on the Ratio of Indicated to Effective Horse Power.

FIG. 3.

"Merkara."

A . Curve of Indicated Horse Power

B . Curve of Indicated Thrust

C . Curve of Slip

D . Constant Friction

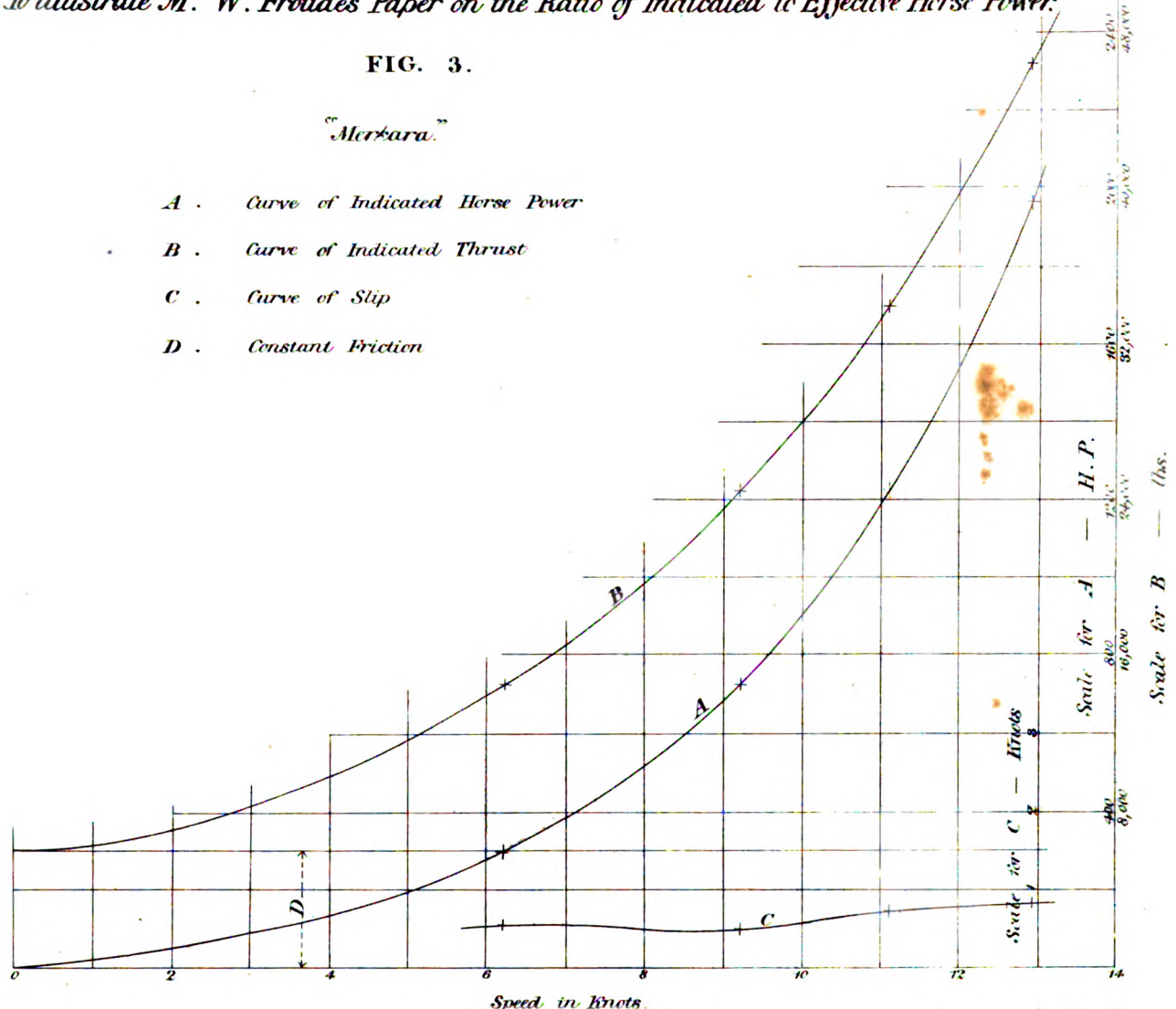


FIG. 4.

"Taupo" and "Hawea"

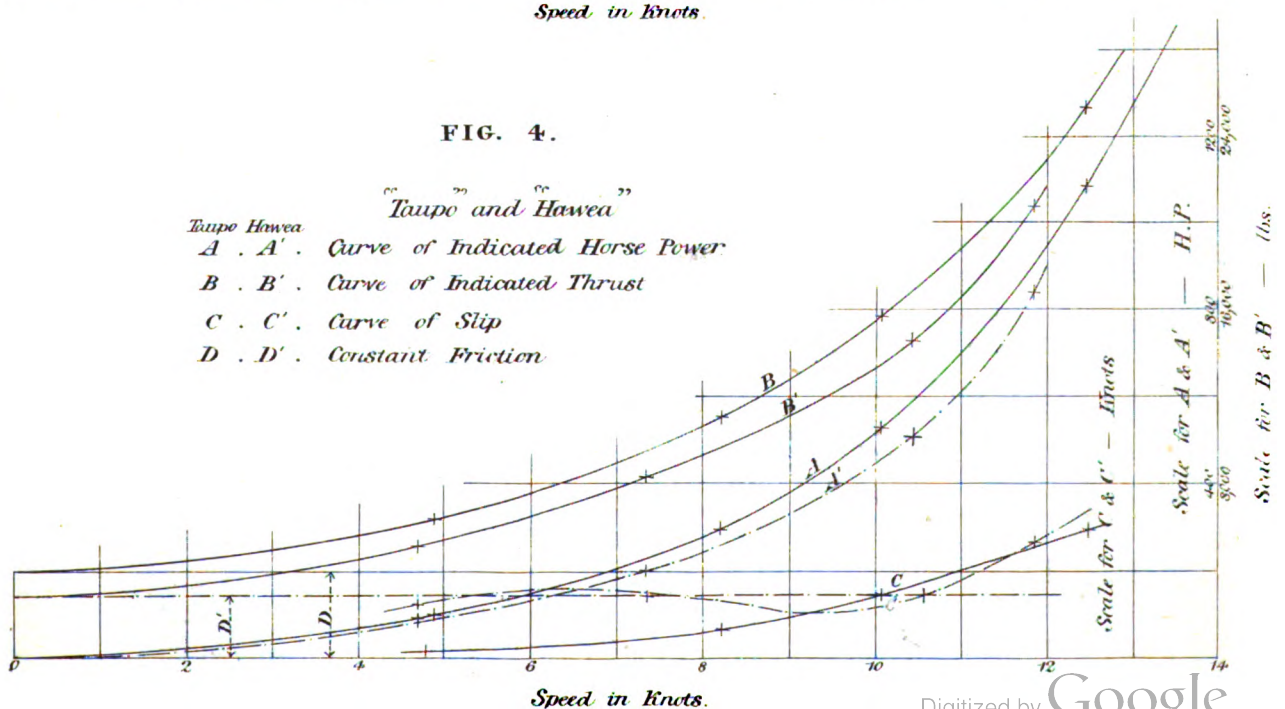
Taupo Hawea

A . A' . Curve of Indicated Horse Power

B . B' . Curve of Indicated Thrust

C . C' . Curve of Slip

D . D' . Constant Friction



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To illustrate Mr. W. Froude's Paper on the Ratio of Indicated to Effective Horse Power.

FIG. 5.

"Arbutus"

A . Curve of Indicated Horse Power

B . Curve of Indicated Thrust

C . Curve of Slip

D . Constant Friction

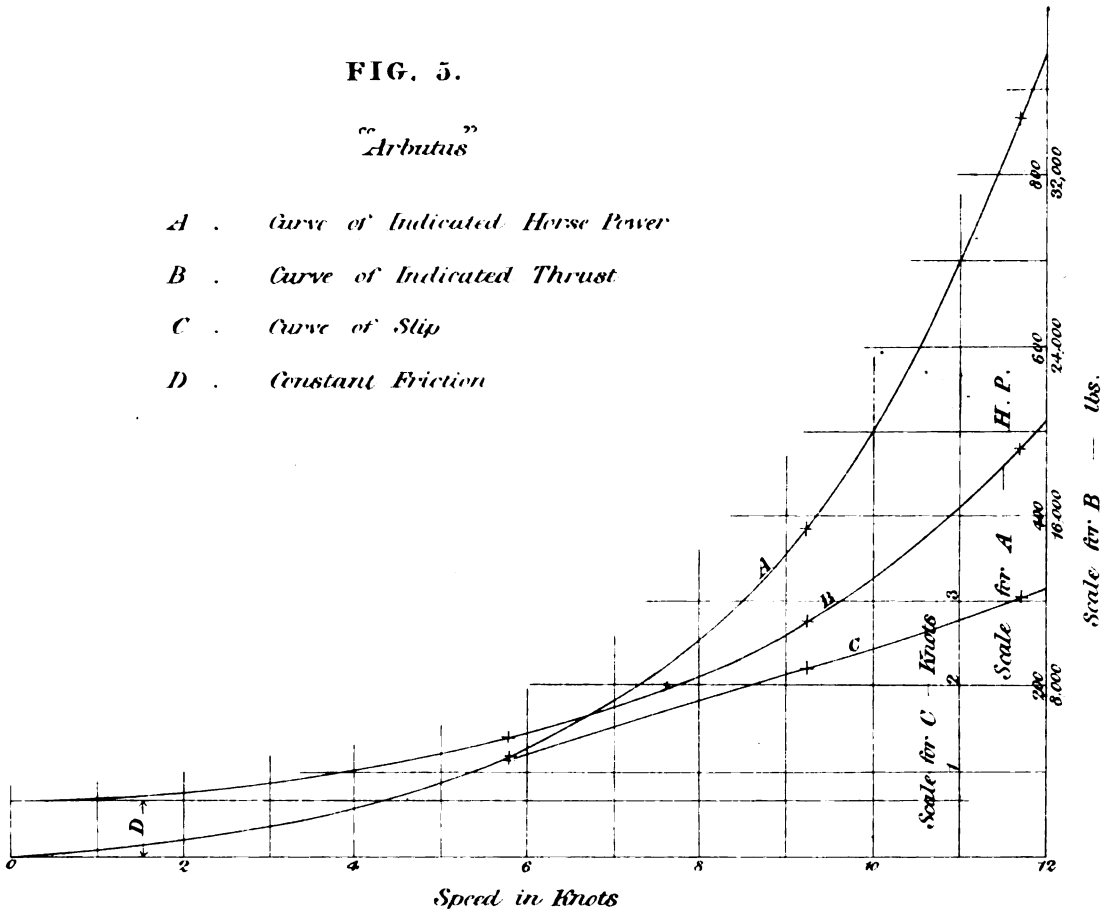


FIG. 6.

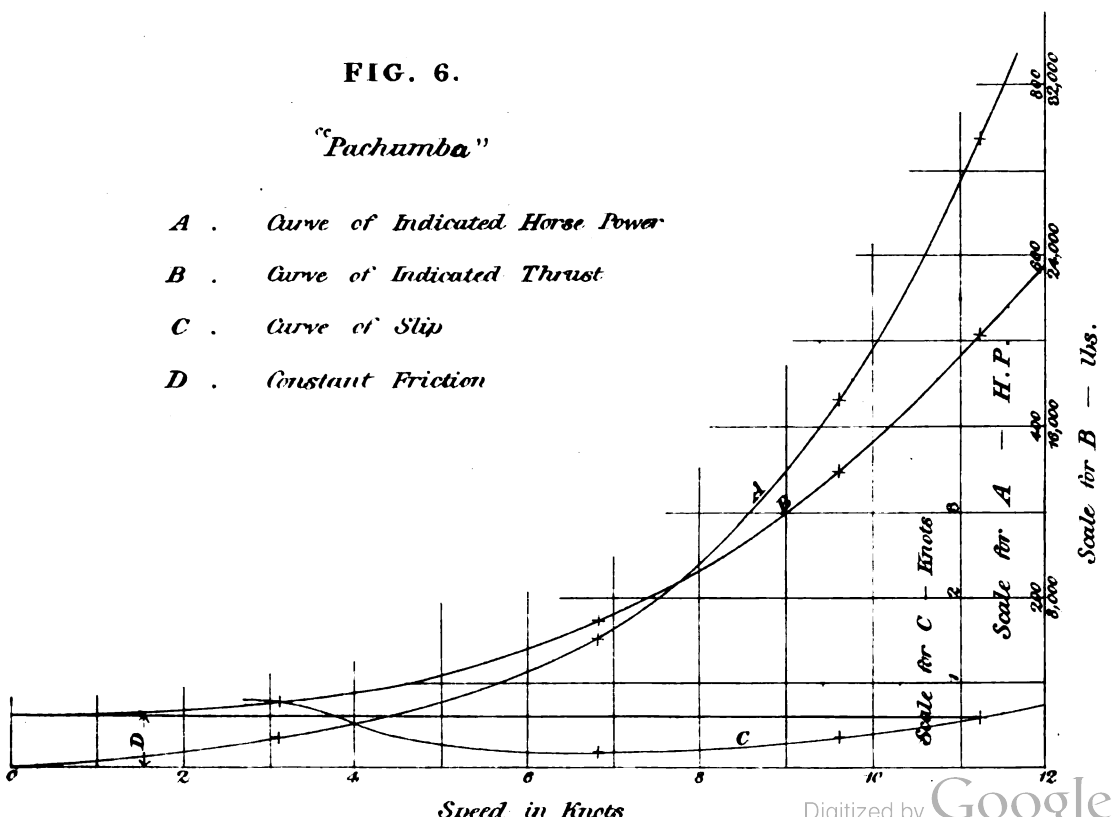
"Pachamba"

A . Curve of Indicated Horse Power

B . Curve of Indicated Thrust

C . Curve of Slip

D . Constant Friction



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To illustrate Mr. W. Froude's Paper on the Ratio of Indicated to Effective Horse Power.

FIG. 7.

Curves shewing the approximate

Elements of Gross I.H.P.

A . H.P. due to Nett Resistance

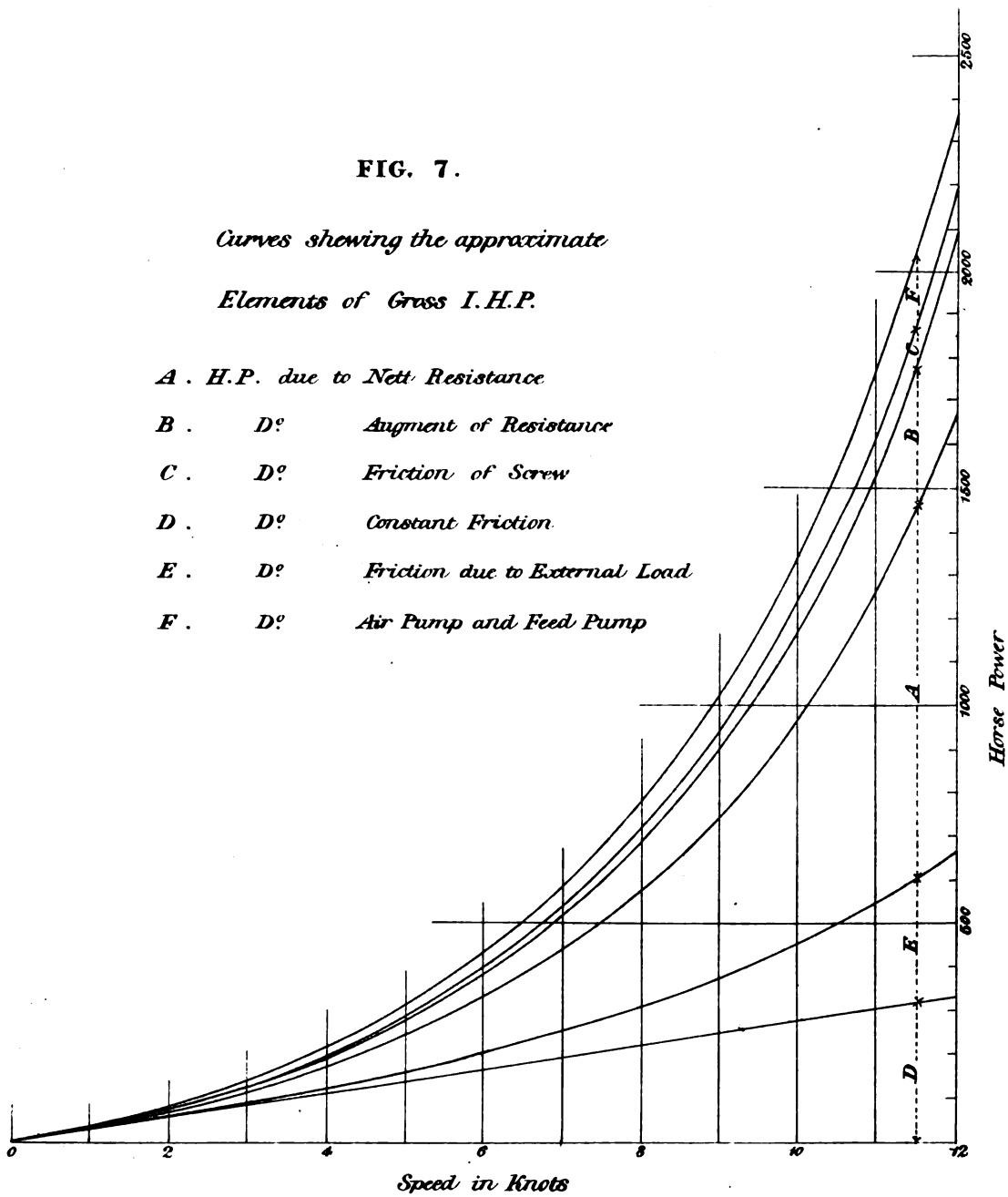
B . Dº Augment of Resistance

C . Dº Friction of Screw

D . Dº Constant Friction

E . Dº Friction due to External Load

F . Dº Air Pump and Feed Pump



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To illustrate Mr. Froude's Paper on Comparative Resistance of Long Ships of Several Types.

Fig. 1.—A.

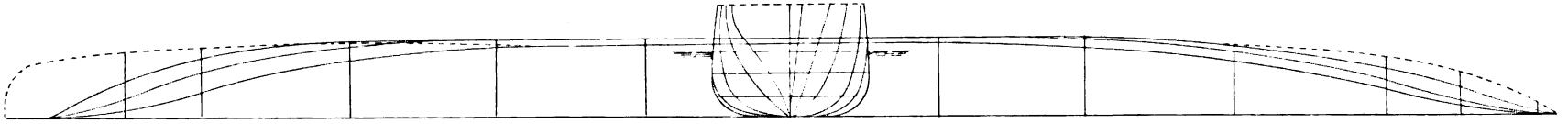


Fig. 2.—B.

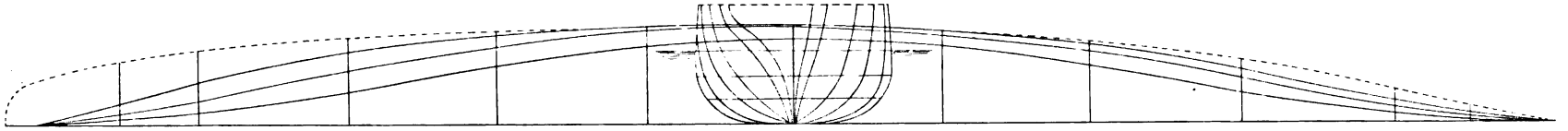


Fig. 3.—C.

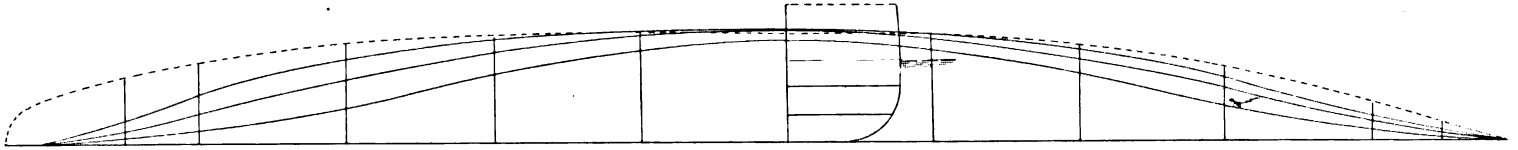
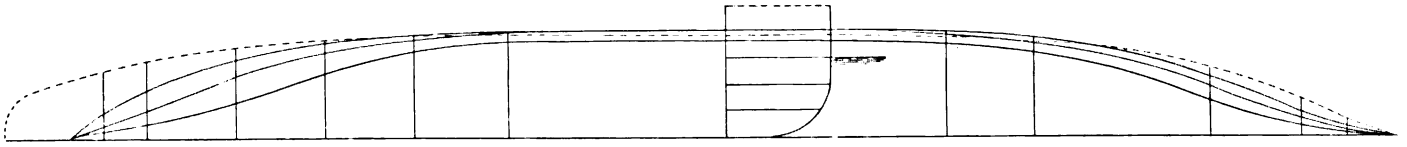


Fig. 4.—D.



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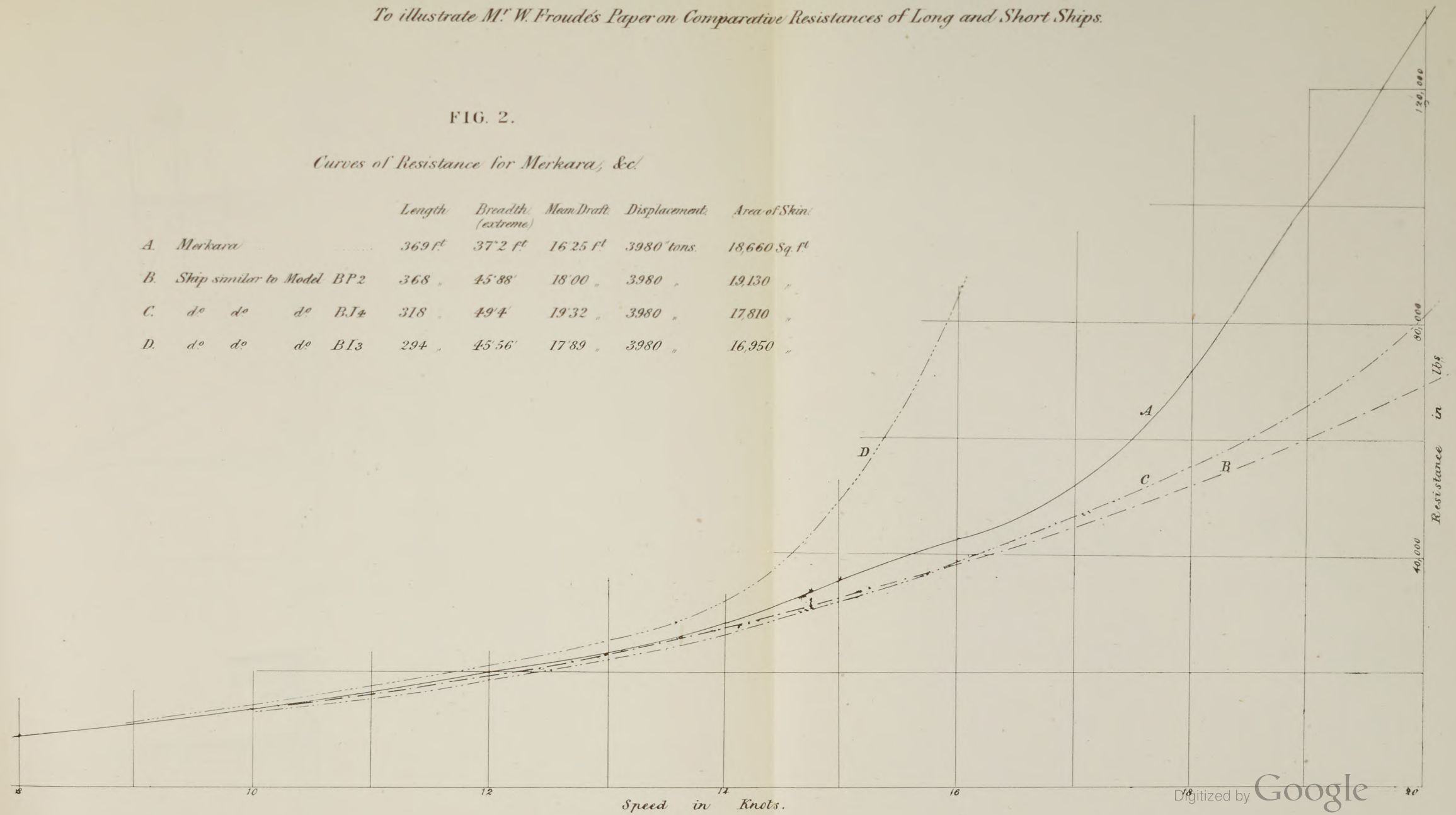
To illustrate Mr. W. Froude's Paper on Comparative Resistances of Long and Short Ships.

FIG. 2.

Curves of Resistance for Merkara, &c.

		Length	Breadth (extreme)	Mean Draft	Displacement	Area of Skin
A.	Merkara	369 ft.	37'2 ft.	16'25 ft.	3980 tons.	18,660 Sq. ft.
B.	Ship similar to Model BP2	368 „	45'88'	18'00 „	3980 „	19,130 „
C.	do do do BJ4	318 „	49'4'	19'32 „	3980 „	17,810 „
D.	do do do BJ3	294 „	45'56'	17'89 „	3980 „	16,950 „



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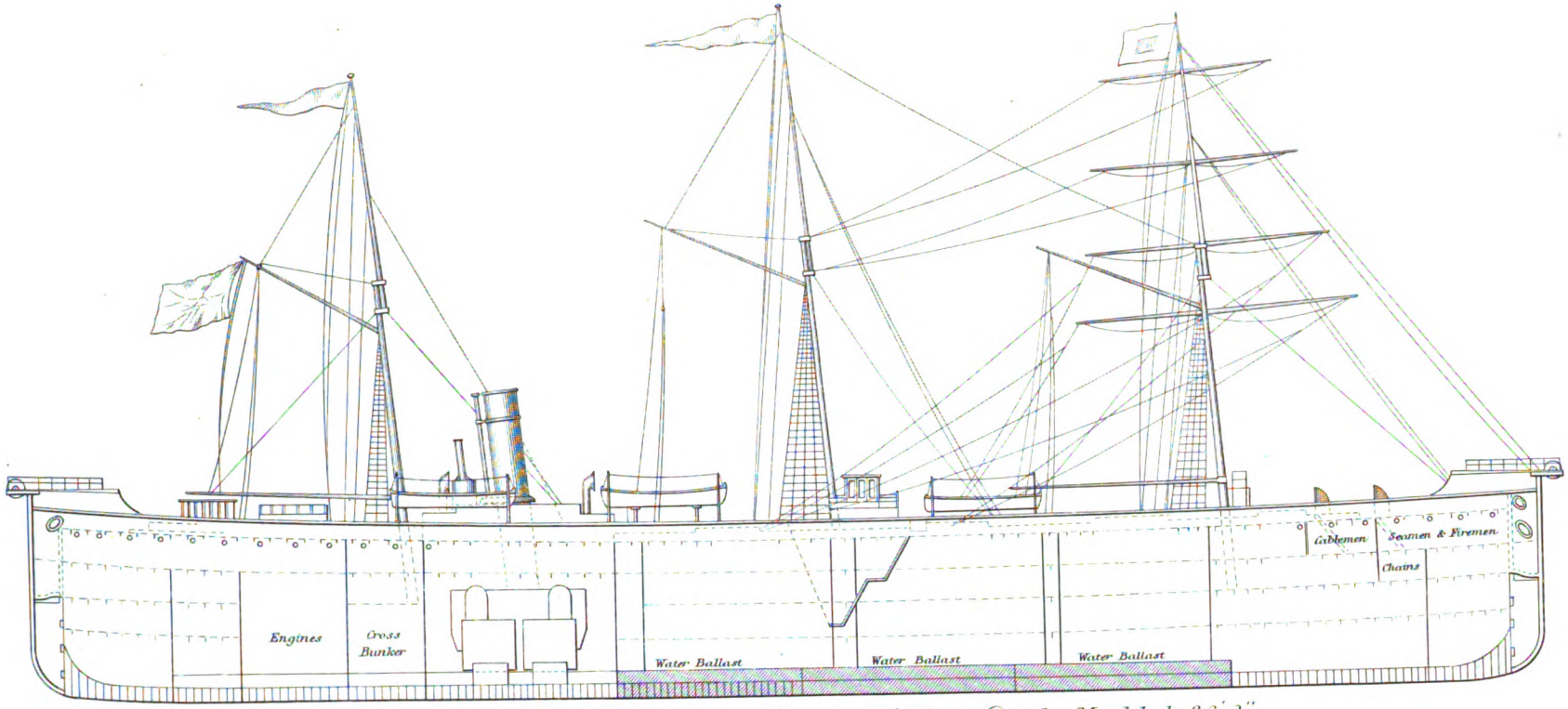
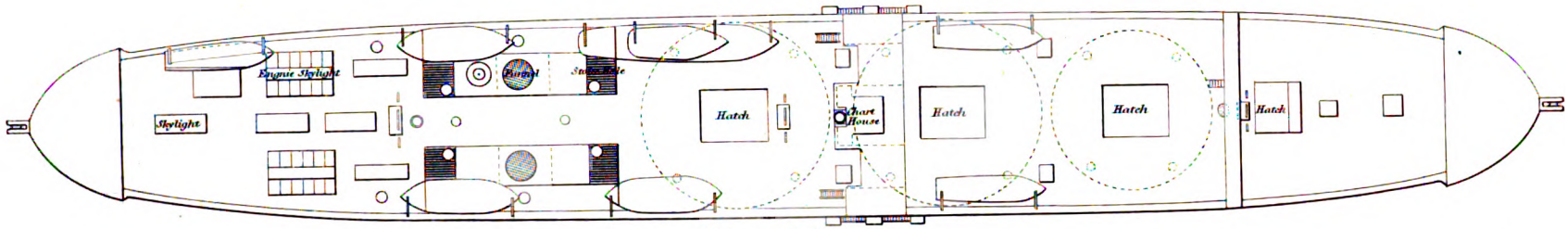
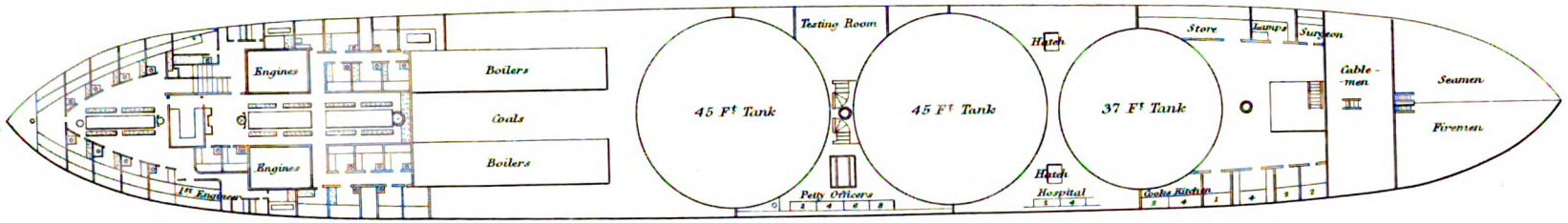
To illustrate Mr C. W. Merrifield's Paper on the Telegraph Ship Faraday.



Length Over All 360'.0" — Extreme Breath 52'.0" — Depth Moulded 36'.0".



Plan of Deck.



Plan of Cabins &c ... Main Deck

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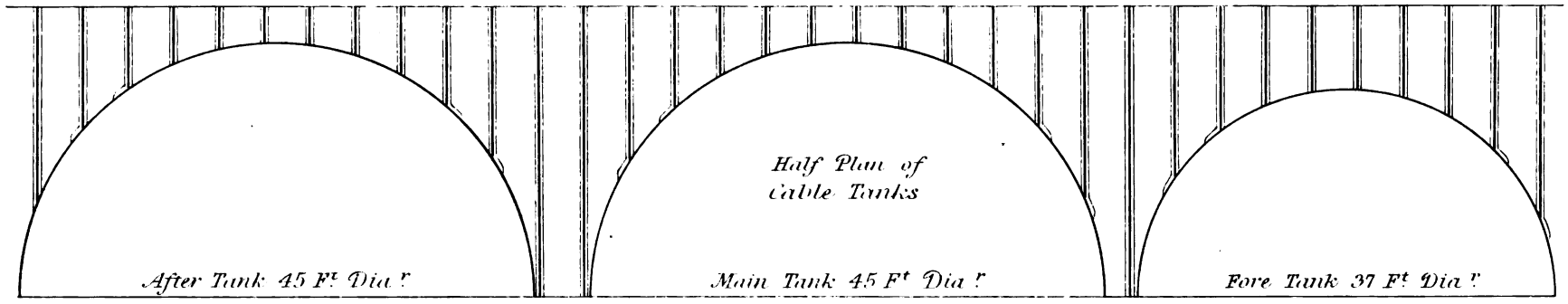
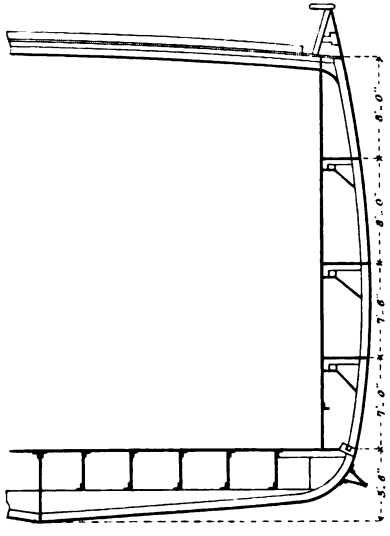
To illustrate Mr. C. W. Merrifield's Paper on the Telegraph Ship Faraday.

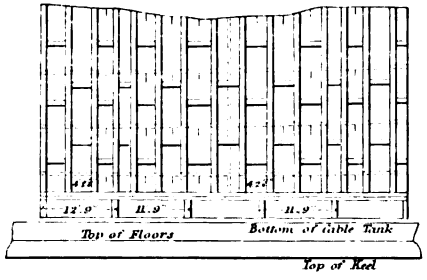


Section through Midship Tank shewing Distance between Beams



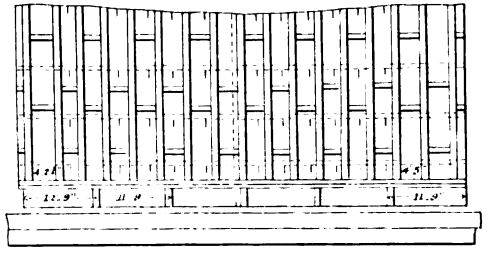
General Scale

Fore Tank

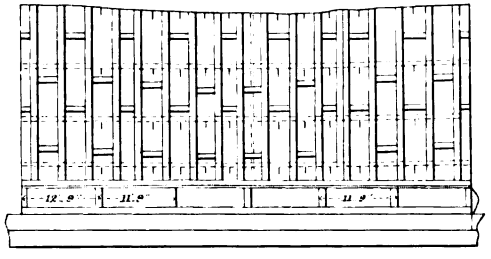


Scale of Details

After Tank



Midship Tank



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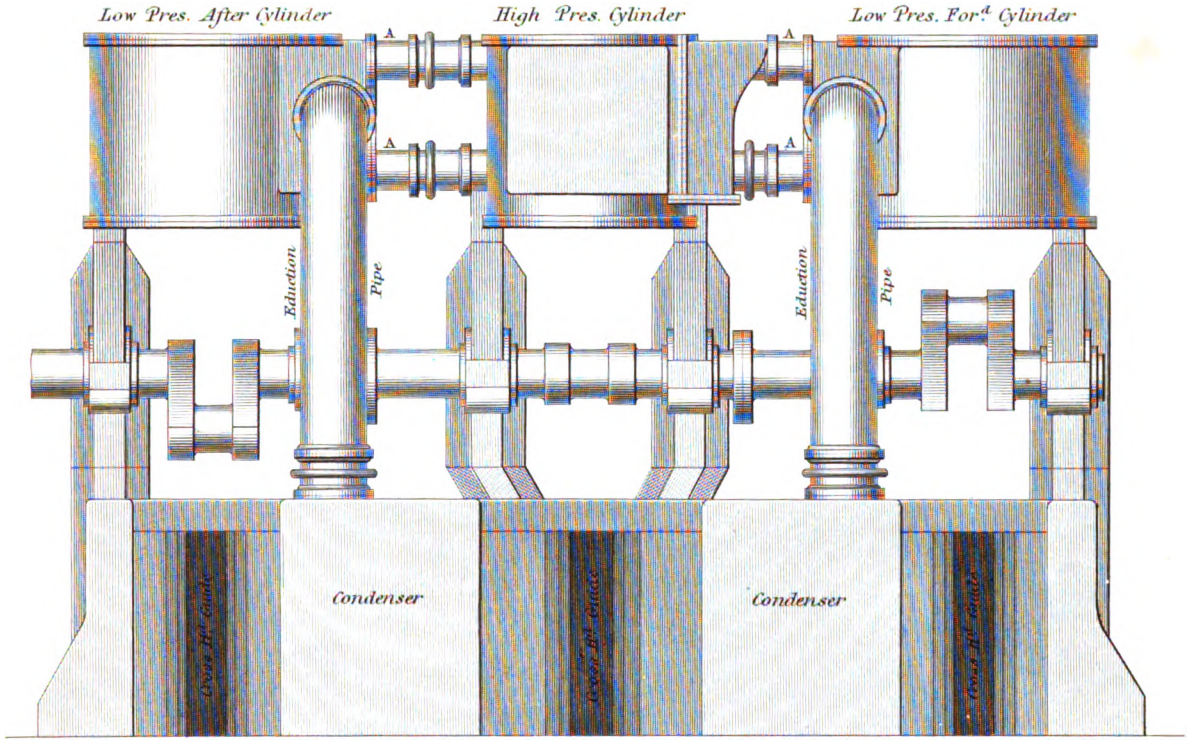
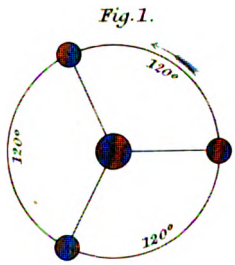
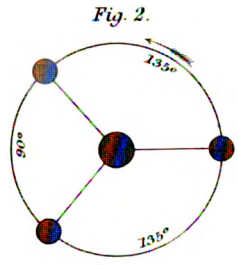
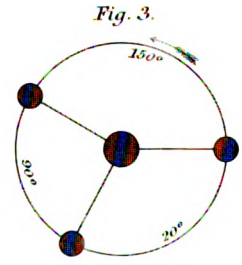
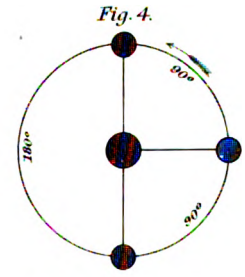
To illustrate Mr. J.R. Ravenhill's Paper on Three Throw Crank Engines of the Compound System.

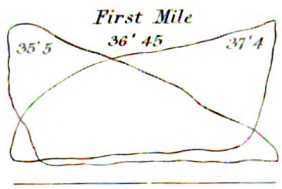


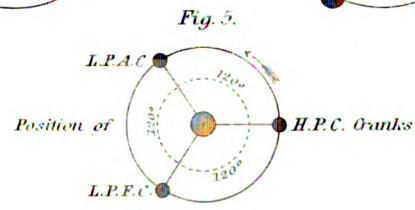


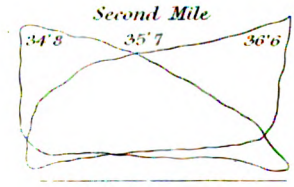


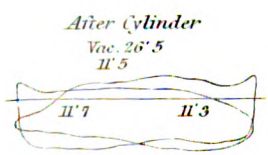


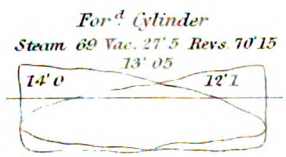


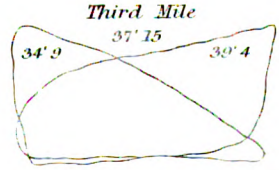


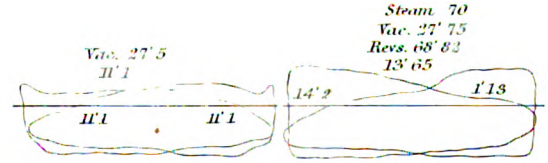


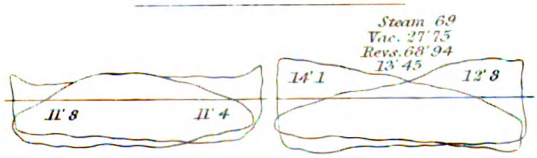












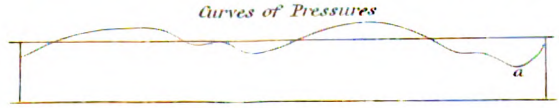


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Fig. 1.

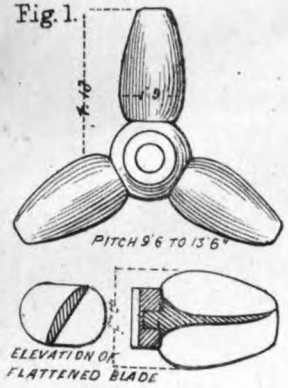
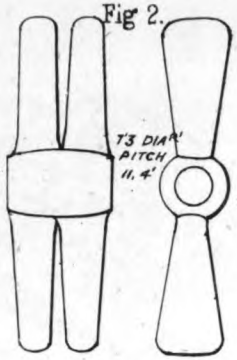


Fig. 2.



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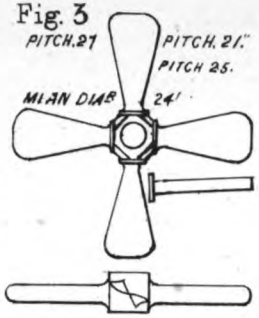

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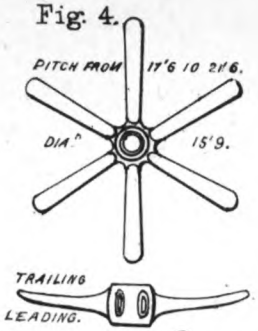

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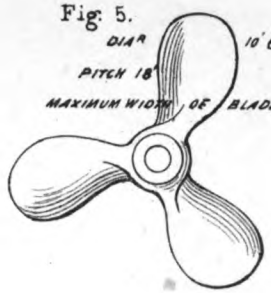

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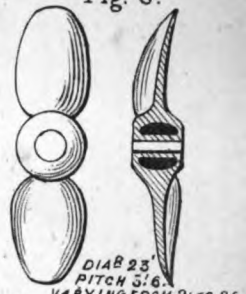

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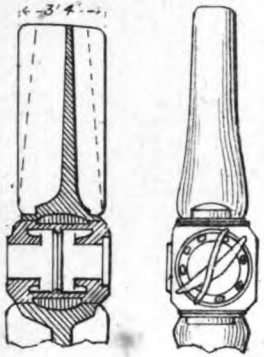

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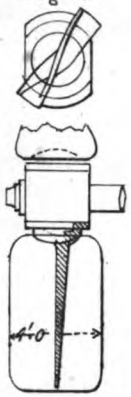

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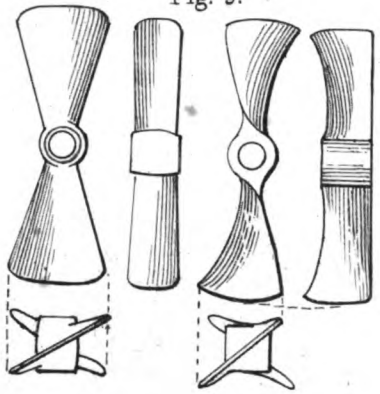

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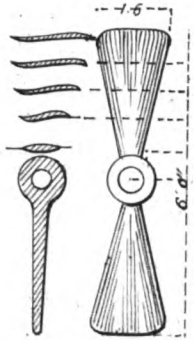

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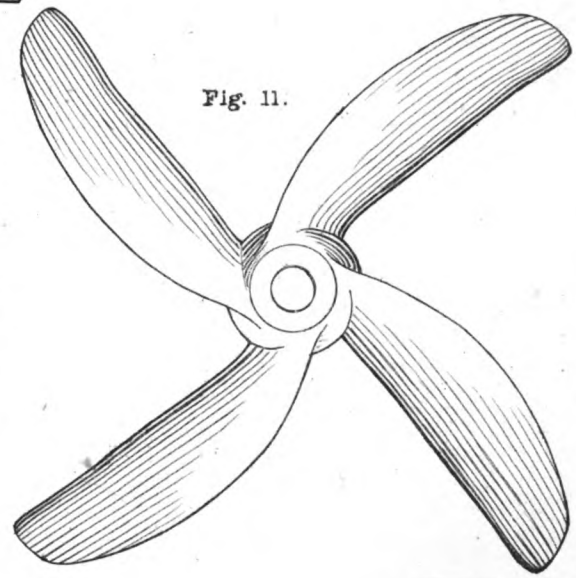

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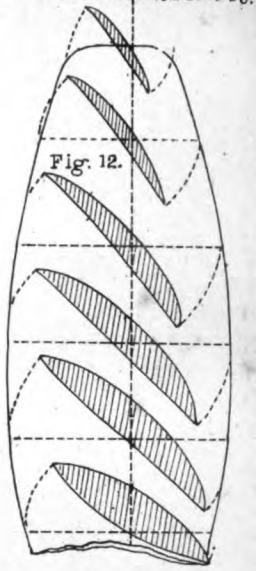

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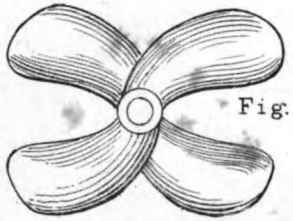

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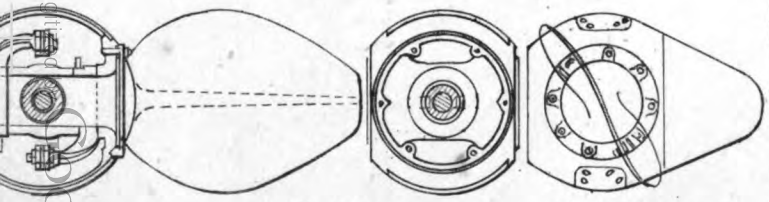

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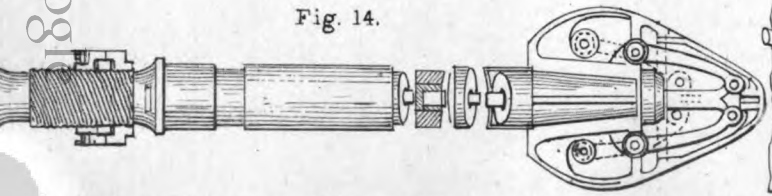

Fig. 1

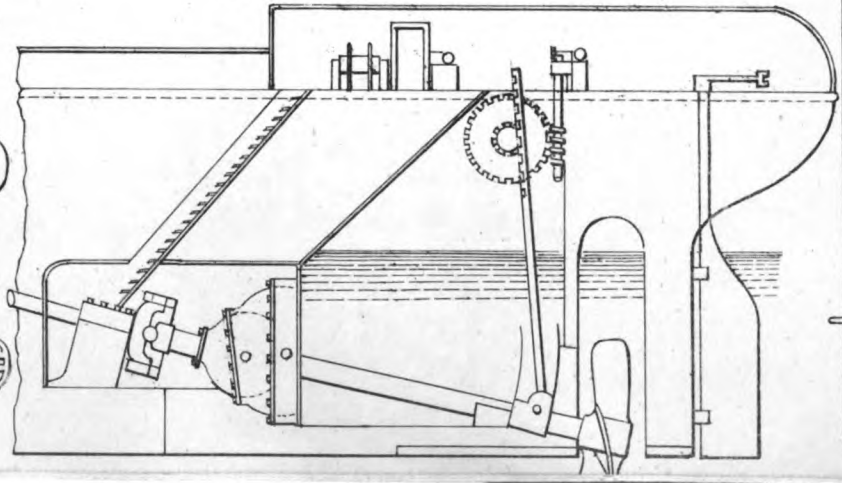

Fig. 1

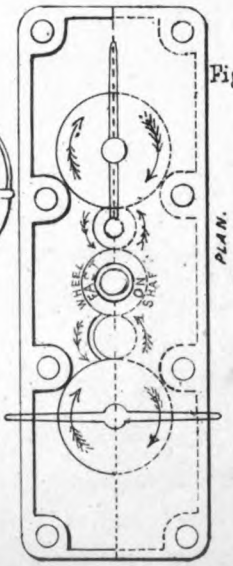

Fig. 1

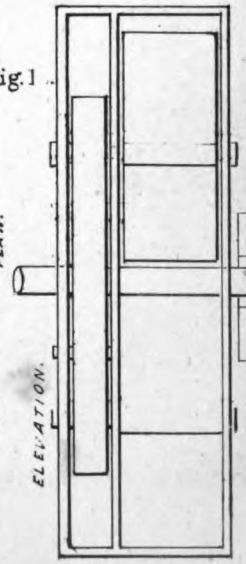

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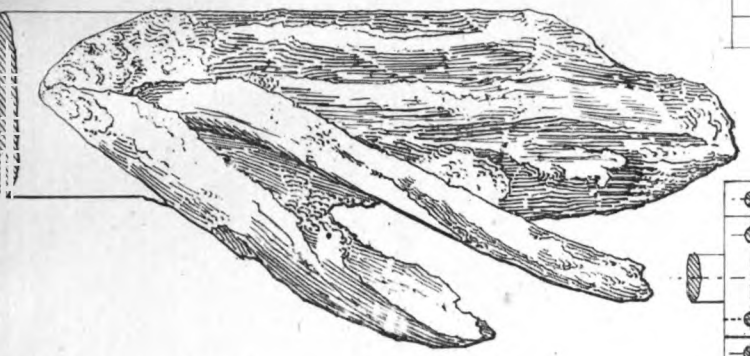
Fig. 1



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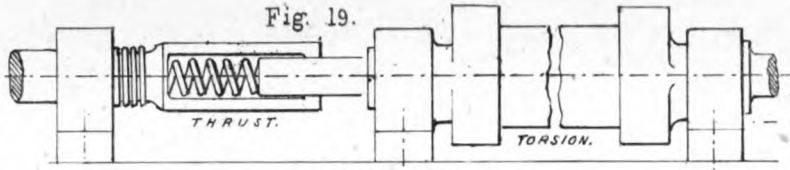
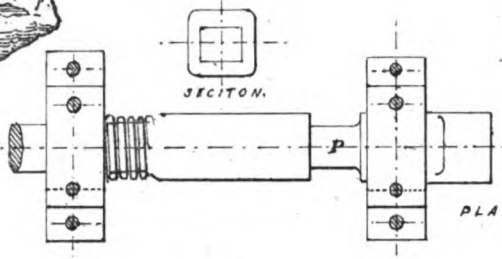
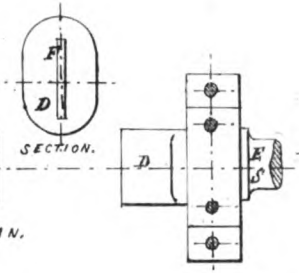


SIDE ELEVATION.



PLAN.



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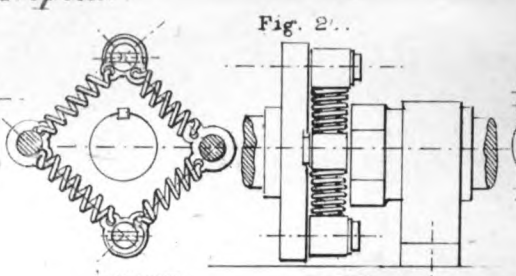

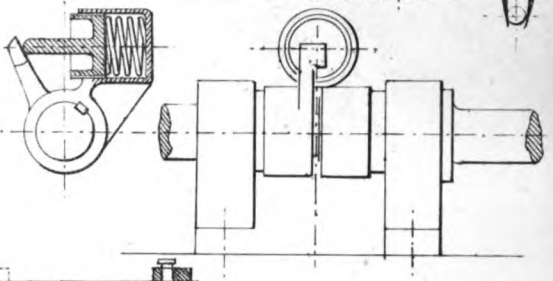

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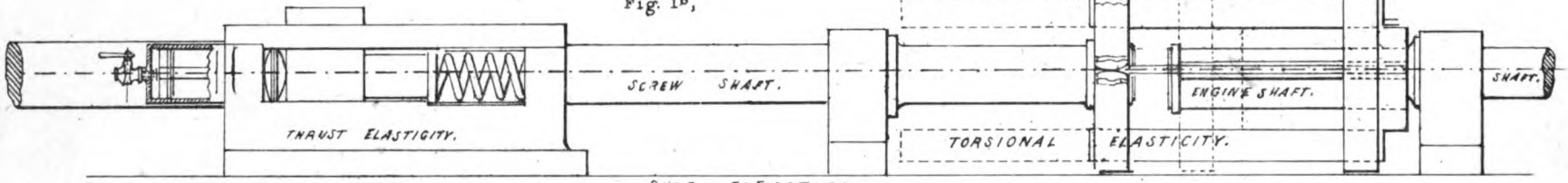

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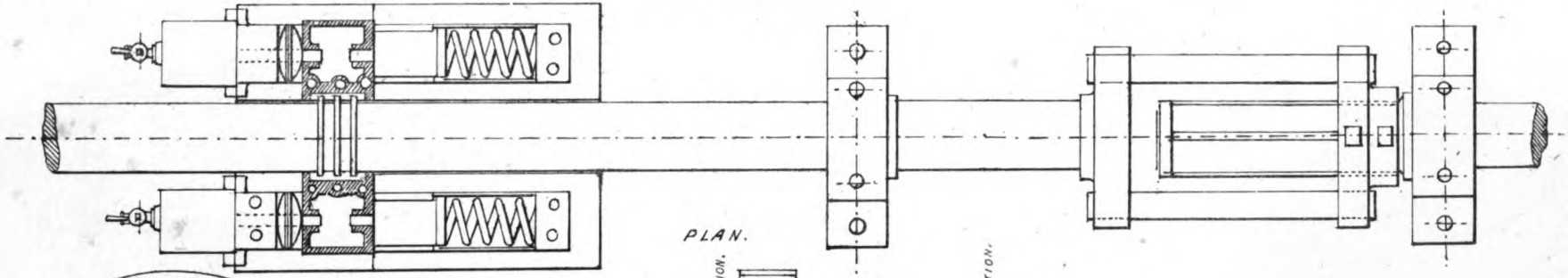

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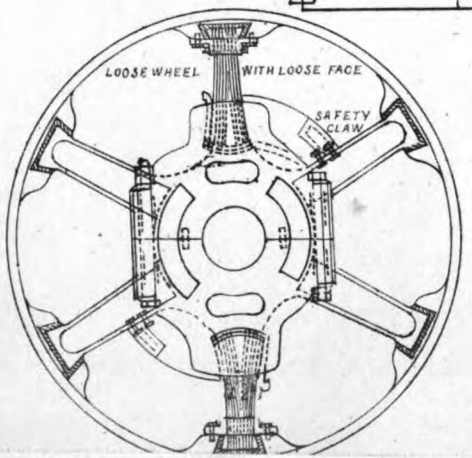

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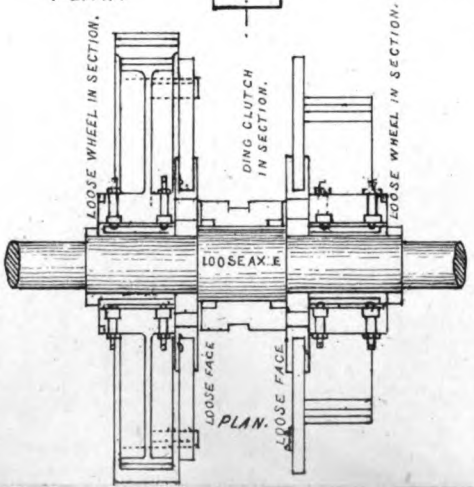

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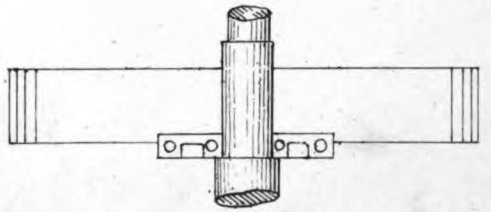

ELEVATION.

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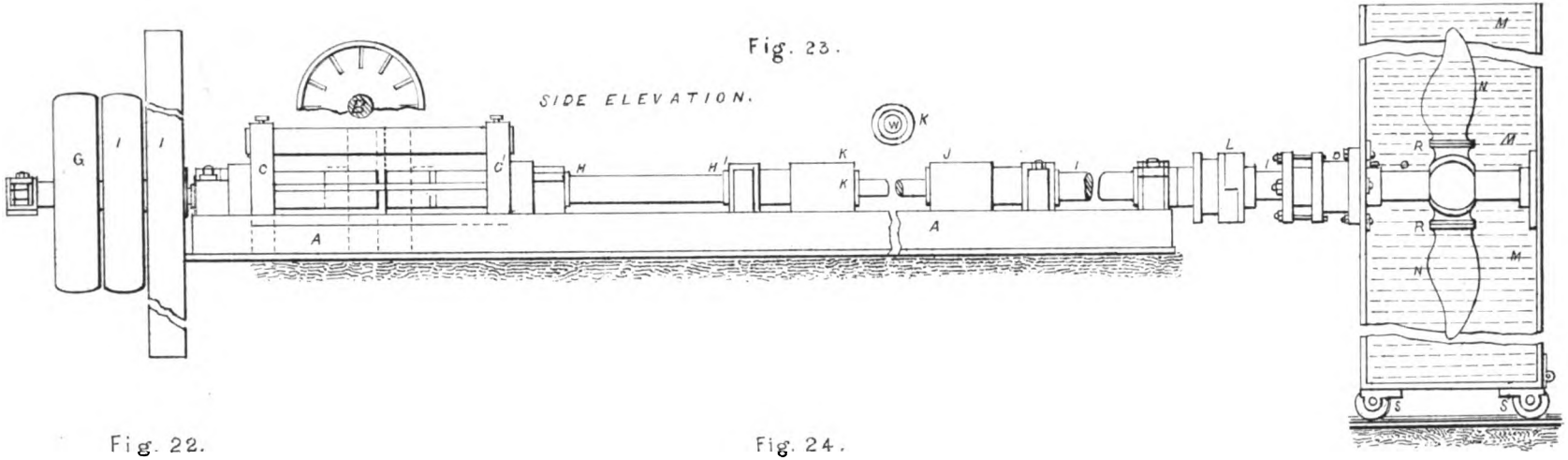
Fig. 23.

SIDE ELEVATION.



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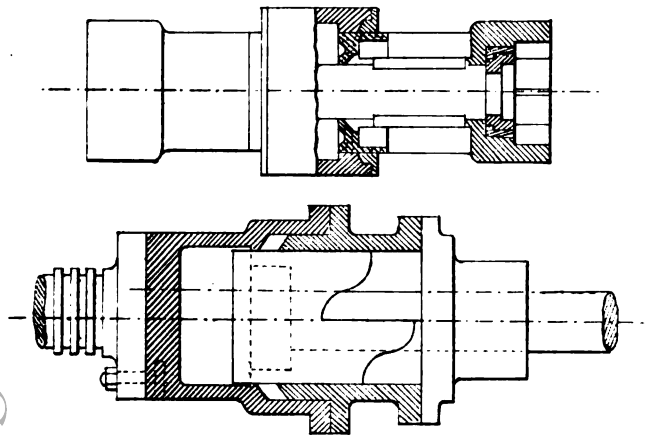

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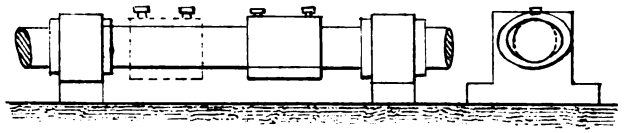

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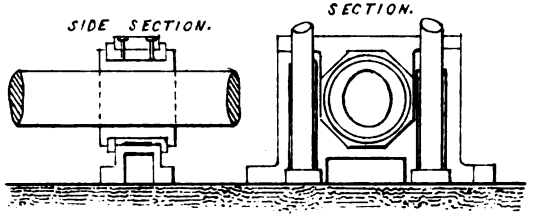

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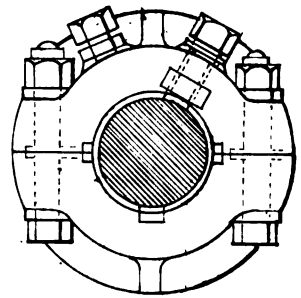

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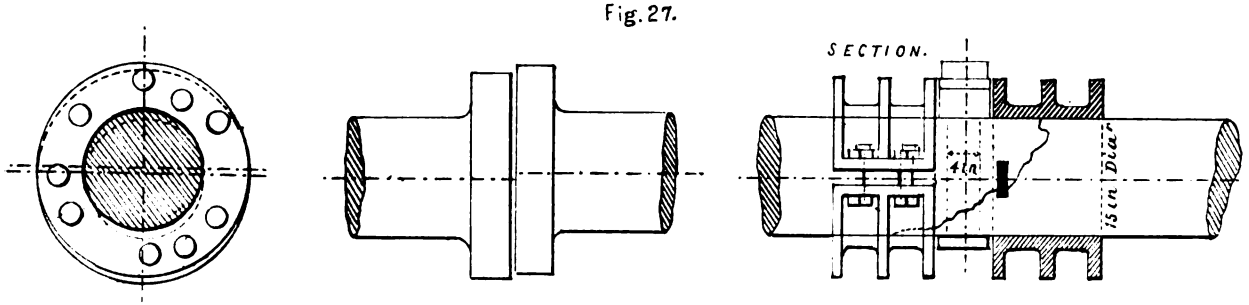

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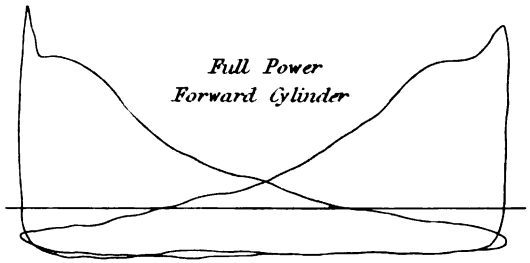
To illustrate Mr. R. Sennett's Paper on Some Trials of Simple and Compound Engines.

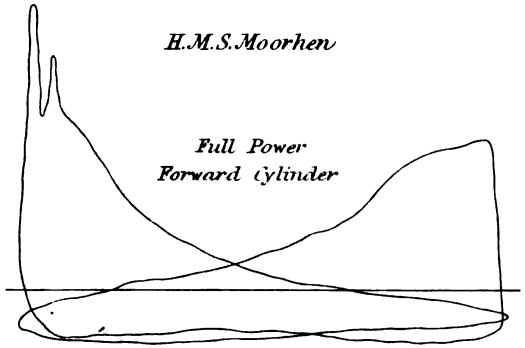
H.M.S. Sheldrake

Full Power
Forward Cylinder



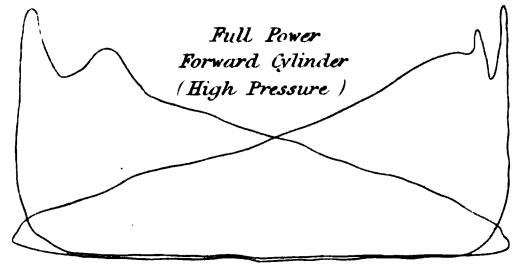
H.M.S. Moorhen

Full Power
Forward Cylinder

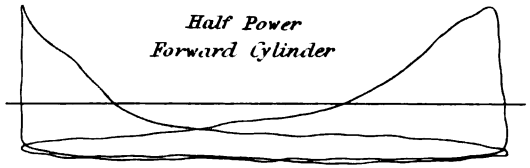


H.M.S. Mallard

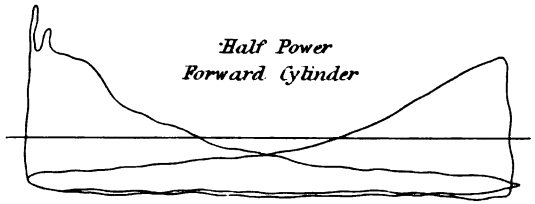
Full Power
Forward Cylinder
(High Pressure)



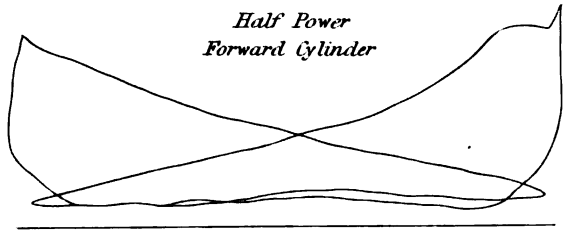
Half Power
Forward Cylinder



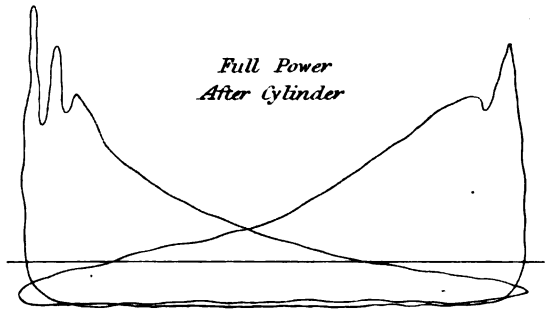
Half Power
Forward Cylinder



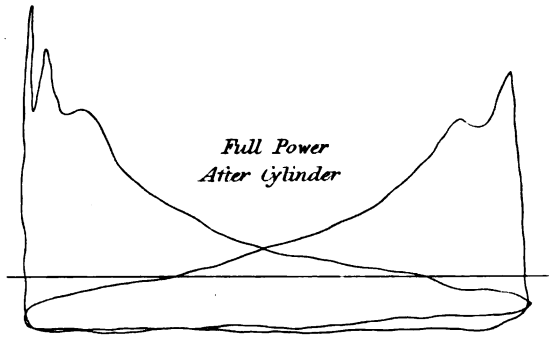
Half Power
Forward Cylinder



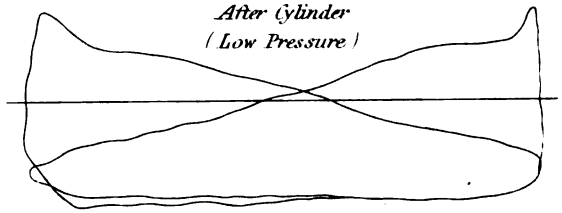
Full Power
After Cylinder



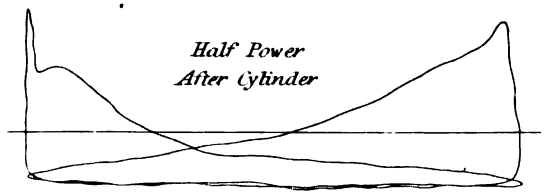
Full Power
After Cylinder



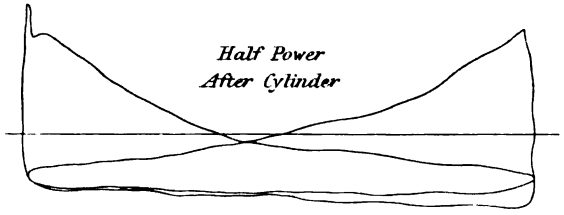
Full Power
After Cylinder
(Low Pressure)



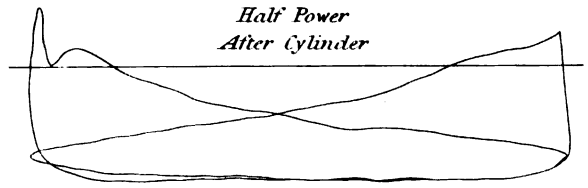
Half Power
After Cylinder



Half Power
After Cylinder



Half Power
After Cylinder



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To illustrate Mr. Edwin W. De Russett's Paper on the Longitudinal Girder or Bulkhead System of Iron Ship Construction.

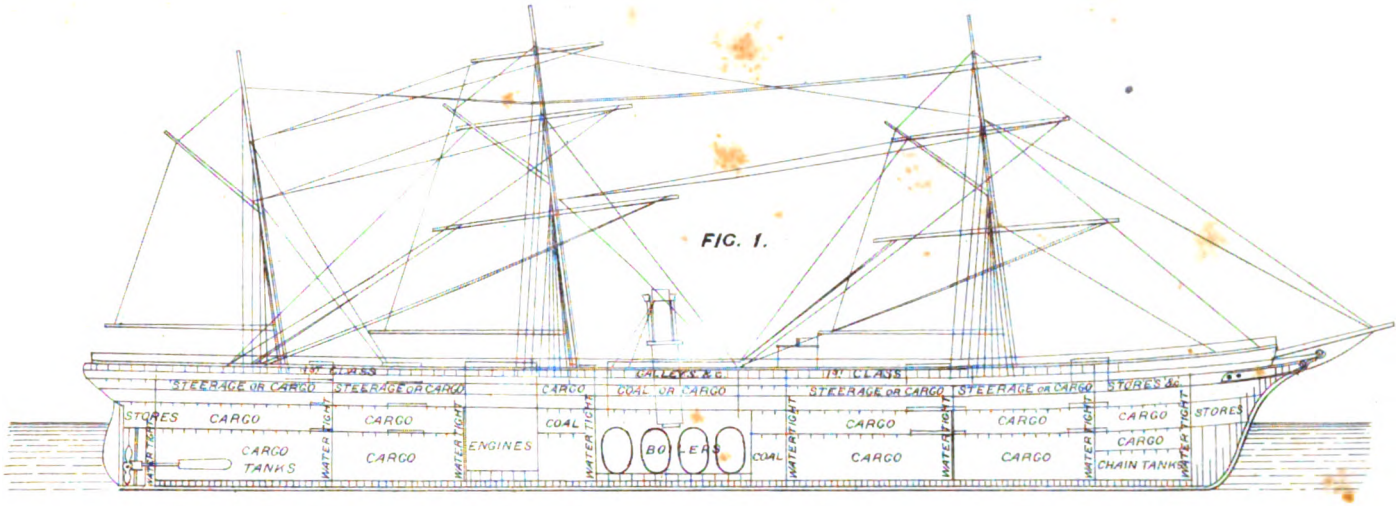


FIG. 1.

FIG. 2.

PLAN OF UPPER DECK SHEWING CABIN ACCOMMODATION &c.

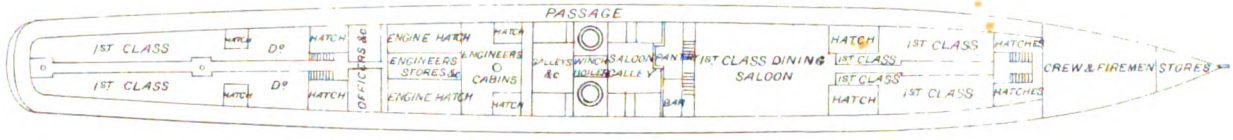


FIG. 3.

PLAN OF 2ND DECK SHEWING LONGITUDINAL AND OTHER WATER-TIGHT BULKHEADS &c.

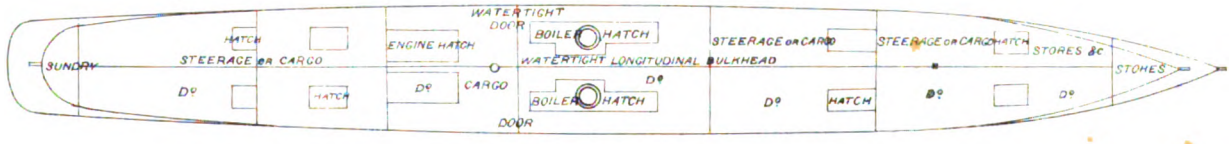
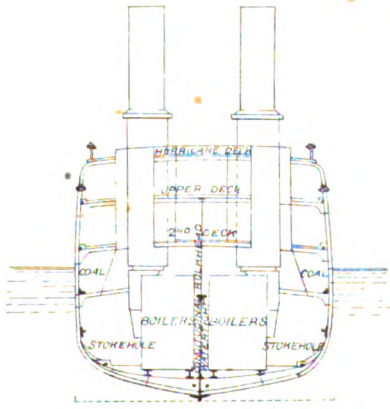
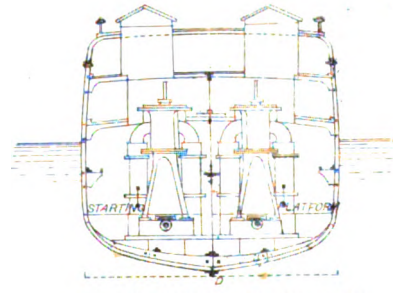


FIG. 4.



SECTION THROUGH ENGINE ROOM

FIG. 5.



SECTION THROUGH ENGINE ROOM.

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